TRANSPORT CANADA

TP 10648E

CA1
DTC800-
90
C17

451972

41.D

CASE STUDIES ON AIR SYSTEM IMPROVEMENTS FOR INTERCITY BUSES

prepared for the
TRANSPORTATION DEVELOPMENT CENTRE
POLICY AND COORDINATION GROUP
TRANSPORT CANADA

BY
Pierre de Gagné
Ed Sloot
Marilyn Eaman

Library and Information Centre / Centre de Documentation (GSLA)
RECEIVED / REÇU LE
NOV 2 1990
Transport Canada / Transports Canada

DELUC
in association with TES LIMITED
and CONCORD SCIENTIFIC CORPORATION

JUNE 1990

451972

DDN 449963

91-02500/

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre, Transport Canada.

Un sommaire en français de ce document est inclus avant la table des matières.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.	2. Project No.	3. Recipient's Catalogue No.
TP - 10648E	6717-15	

4. Title and Subtitle	5. Publication Date
Case Studies on Air System Improvements for Intercity Buses	June 1990
	6. Performing Organization Document No.: 09-1498-B-00
7. Author(s): Pierre de Gagné, Ed Sloot, Marilyn Eaman	8. Transport Canada File No.: D1465-451-5
9. Performing Organization Name and Address: Deluc, C.P. 293, Chelsea, Quebec, J0X 1N0	10. DSS File No.: 11SD. T8200-6-6510
	11. DSS or Transport Canada Contract No.: T8200-6-6510/SD-01
12. Sponsoring Agency Name and Address: Transportation Development Centre (TDC), 200 René Lévesque Boulevard West, Suite 601, West Tower, Montreal, Quebec H2Z 1X4	13. Type of Publication and Period Covered
	14. Project Officer: Brian Marshall

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

16. Abstract

This study consists of an investigation of problems associated with the climatic control system of intercity coaches. It addresses the problems of driver's windshield fogging, sound levels and air quality inside a Prévost Marathon XL coach. The objective was to gather pertinent information through testing and analysis and develop recommendations that could be used to improve passenger comfort in a new model of coach recently developed at Prévost Car. Two types of washable filters, and two types of disposable filters were tested. Two of these four filters were electrostatically augmented. Recommendations are made concerning improvements to air quality, filtration technology and windshield fogging.

17. Key Words	18. Distribution Statement
Bus, coach, air conditioning, air quality, filtration, windshield fogging, safety, Prévost Car	Limited number of copies available from the Transportation Development Centre on request.

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	-	108	-

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada	2. N° de l'étude	3. N° de catalogue du destinataire
TP -10648E	6717-15	

4. Titre et sous-titre	5. Date de la publication
Case Studies on Air System Improvements for Intercity Buses	juin 1990
	6. N° du document de l'organisme exécutant: 09-1498-B-00

7. Auteur(s)	8. N° de dossier — Transports Canada
Pierre de Gagné, Ed Sloot, Marilyn Eaman	D1465-451-5

9. Nom et adresse de l'organisme exécutant	10. N° de dossier — ASC
Deluc C.P. 293, Chelsea, Québec JOX 1NO	11SD. T8200-6-6510
	11. N° de contrat — ASC ou Transports Canada: T8200-6-6510/SD-01

12. Nom et adresse de l'organisme parrain	13. Genre de publication et période visée
Centre de développement des transports 200 ouest, boul. René-Lévesque Tour ouest, suite 601 Montréal (Québec) H2Z 1X4	14. Agent de projet: Brian Marshall

15. Remarques additionnelles (Programmes de financement, titres de publications connexes, etc.)

16. Résumé

Cette recherche avait pour but de trouver des solutions aux problèmes de climatisation dans les autocars Prévost modèle Marathon XL, notamment l'embuage de pare-brise, les niveaux sonores et la qualité de l'air. Il s'agissait d'analyser les informations recueillies à la suite de nombreux essais et de formuler des recommandations applicables à un nouveau modèle d'autocar Prévost où le confort des passagers serait grandement amélioré. Deux types de filtres lavables et deux de type jetable ont été essayés, deux de ces quatre filtres faisant intervenir en plus un effet électrostatique. Le rapport propose des améliorations visant les techniques de filtration de l'air et de désembuage du pare-brise afin d'améliorer la qualité de l'air à l'intérieur des autocars.

17. Mots clés	18. Diffusion
Autocars, climatisation, qualité de l'air filtration, embuage du pare-brise, securité, autocars Prévost	Le Centre de développement des transports

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	-	108	-

ACKNOWLEDGEMENTS

The authors would not have been able to prepare this report without assistance from numerous people and organizations.

We especially wish to thank the Transportation Development Centre at Transport Canada, the sponsoring agency, for responding to our numerous request for help in locating and gathering information and contacts. In particular, we are grateful to the project officer, Brian Marshall, for his support.

The research team had much willing support from Voyageur, the local coach operator, which provided coaches and drivers in support of the testing program. We wish to thank Mr. Bob Sargeant, Head of Ottawa Operations and Mr. Louis Desmarais, Technical Services Manager for all the time they took in answering our numerous questions and hosting our site visits.

We would also like to thank the following individuals for their assistance:

- Jules Perrault, V.P. Engineering, Prévost Car
- Marc-José Handfield, Project manager, Prévost Car
- Graham Parkins, President, Airscreen Filters

SUMMARY

This study sought to investigate problems associated with the climatic control system of intercity coaches. The problems addressed were windshield fogging, sound levels and air quality inside a Prévost Marathon XL Intercity Coach. The objective of these investigations was to gather pertinent information through testing and analysis and to develop recommendations that could be used to improve passenger comfort in a new model of intercity coach.

A common problem with intercity buses in late fall and early spring is the buildup of fog on the interior of the driver's windshield. The windshield tends to fog-up in the corners or along the sides, which makes it very difficult for the driver to use the side mirrors. The direction and volume flow of the air exiting the defrost diffusers were measured on MCI and Prévost coaches.

The results support the different degrees of fogging noted by Voyageur personnel on the two coach types, that is, more flow, less fogging.

Three alternatives were developed that would resolve the fogging problem. The preferred solution involved the installation of directional fans at the bottom corners of the windshield. This solution was actually implemented in an articulated bus and the problem of windshield fogging was greatly reduced.

In order to develop a strategy to improve passenger compartment noise reduction and air quality, a testing program was developed to evaluate the climatic control system of the intercity coach. It was felt that improving the filtering ability of the HVAC system would improve comfort conditions. Three alternative 25 mm air filters were selected by Prévost staff for evaluation: a fibreglass filter, an electronic filter and a washable polypropylene filter. The electronic and washable polypropylene filters are both electrostatically augmented.

The three alternative filters were tested and compared against the stock filter in terms of pressure drop, capacity to remove respirable particulate and their effect on sound levels. The results indicate that the replacement filters reduce the sound level at given seat locations from 0.25 dB to 3.75 dB. This small amount of noise reduction is believed to be associated with less fan noise sound transmission through the return air system owing to the improved sound deadening characteristics of the alternate filters and less diffuser noise because of reduced air flow associated with the increased pressure drop of the alternate filters.

The pressure drop measurements across the clean filters and coils showed the alternate filters all had increased resistance to flow relative to the stock filter. The disposable fibreglass filter had 6% more pressure drop, the electronic filter 26% more and the washable polypropylene 19% more.

The increase in pressure drop after some use is relative to how much dust and particulate has been captured by the filter. The washable polypropylene and the electronic filters demonstrated the largest increase in pressure drop over time. The Prévost stock filter demonstrated the lowest change in pressure drop over time.

No significant differences were observed in the abilities of the four filter types to remove respirable suspended particulate. It appears that the principal removal mechanism involved is impaction, as no beneficial effects were noted with the electrostatically augmented filters; conversely, that the ambient charge of static electricity present on a coach largely defeats the purposeful charge of static electricity associated with the electronic and washable polypropylene filters.

It is recommended that filter selection criteria emphasize airflow considerations, cost and replacement frequencies if the space criterion remains a high priority. If more space could be made available, more effective filtration technology could be applied.

SOMMAIRE

Cette recherche avait pour but de trouver des solutions aux problèmes de climatisation dans les autocars Prévost modèle Marathon XL, notamment l'embuage du pare-brise, les niveaux sonores et la qualité de l'air. Il s'agissait d'analyser les informations recueillies à la suite de nombreux essais et de formuler des recommandations applicables à un nouveau modèle d'autocars où le confort des passagers serait grandement amélioré.

Un des problèmes les plus courants à bord des autocars est celui de l'embuage du pare-brise côté conducteur vers la fin de l'automne et le début du printemps. L'embuage se fait sentir surtout dans les coins et sur les côtés du pare-brise, gênant la visibilité des rétroviseurs extérieurs. Pour cerner le problème, la direction et le débit de l'air sortant des désembueurs équipant les autocars fabriqués par MCI et Prévost ont été déterminés.

Les résultats confirment les constatations du personnel d'entretien de Voyageur Inc., à savoir que le désembuage est d'autant plus rapide que le débit d'air est élevé.

Trois solutions ont été envisagées, la préférée étant de placer des ventilateurs orientables dans les coins inférieurs du pare-brise. Elle s'est révélée nettement efficace, comme l'a prouvé une installation semblable dans un autocar articulé.

Afin de réduire les niveaux sonores et d'amélioration de la qualité de l'air dans le compartiment des passagers, les chercheurs ont mis sur pied un programme d'essais visant à évaluer les système de climatisation. Conclusion: le confort des passagers serait meilleur si l'on perfectionnait les circuits de filtration du système de chauffage, ventilation et climatisation. Trois types différents de filtres à air 25 mm ont été évalués par Prévost: un en fibres de verre, un électrofiltre et un filtre lavable en fibres de polypropylène, l'effet dans ces deux derniers étant augmenté par un élément électrostatique.

Ces trois types de filtres ont été comparés au filtre d'usage courant sous l'angle de la perte de charge, de l'aptitude à retenir les particules inhalables et du bruit. Les résultats montrent que les filtres envisagés réduisent les niveaux sonores en certains endroits du compartiment passagers de 0,25 à 3,75 dB. Cette faible atténuation résulte du fait que ces filtres absorbent mieux le bruit causé par les ventilateurs et transmis à travers le circuit d'air de reprise et que la perte de charge plus élevée qu'ils provoquent, donc la réduction du débit d'air, rend les diffuseurs moins bruyants.

Les pertes de charge mesurées à travers des filtres et des tubes propres indiquent une résistance à l'écoulement de l'air plus élevée des nouveaux filtres par rapport au filtre d'utilisation courante. Les filtres jetables à fibres de verre provoquent, en effet, 6 p. 100 de perte de charge supplémentaire, les électrofiltres et les filtres à fibres de polypropylène 26 et 19 p. 100 de plus, respectivement.

L'accroissement de la perte de charge au cours du temps est lié à l'efficacité du filtre, c'est-à-dire son aptitude à retenir les poussières et les particules. Les filtres à fibres de polypropylène et les électrofiltres ont montré la plus forte croissance de la perte de charge au cours du temps et le filtre d'utilisation courante la plus faible.

Aucune différence significative n'a été constatée dans l'efficacité des quatres types de filtres à retenir les particules inhalables en suspension. Il semble que la principale force à intervenir soit celle d'inertie ou d'impact, étant donné l'absence d'effet bénéfique obtenu par l'intervention de la force électrostatique. Il se peut aussi que la forte charge d'électricité statique ambiante a largement annulé l'effet de la force électrostatique produite par les électrofiltres et les filtres à fibres de polypropylène.

Si les contraintes d'espace demeurent inchangées, il faudra sélectionner les filtres en fonction de la vitesse de filtration, du coût et de la fréquence de remplacement. Mais s'il était possible d'envisager un encombrement accru, un système de filtration de plus haute efficacité serait justifié.

TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
1.1	Scope	1
1.2	Background	1
2.0	TEST METHODOLOGY	3
2.1	Windshield Fogging	3
2.2	Alternative Filter Evaluation	3
2.2.1	Sound Level Measurements	6
2.2.2	Pressure Drop Measurements	6
2.2.3	Respirable Particulate Removal Measurements	9
3.0	RESULTS	11
3.1	Windshield Fogging	11
3.2	Sound Level Measurements	12
3.3	Pressure Drop Measurements	16
3.4	Respirable Particulate Removal Measurements	19
4.0	ECONOMIC ANALYSIS	29
5.0	CONCLUSIONS AND RECOMMENDATIONS	33
APPENDIX A	"DYNAMIC" ELECTRONIC, ELECTROSTATICALLY AUGMENTED FILTER - SUPPLIER INFORMATION AND ASHRAE TEST DATA	
APPENDIX B	"AAA" WASHABLE POLYPROPYLENE, ELECTRO-STATICALLY AUGMENTED FILTER - SUPPLIER INFORMATION AND ASHRAE TEST DATA	

LIST OF FIGURES

		Page
Figure 1 -	Air Distribution Schematic - Marathon XL Intercity Coach	4
Figure 2 -	Plenum Detail - Marathon XL Intercity Coach	5
Figure 3 -	Seat Number Scheme - Marathon XL Intercity Coach	7
Figure 4 -	Measured Sound Levels - Right Side	14
Figure 5 -	Measured Sound Levels - Left Side	15
Figure 6 -	Differential Sound Levels	18
Figure 7 -	Corrected Pressure Drop Increase	21
Figure 8 -	Reduction in RSP Concentration - Stock Bus Filter	23
Figure 9 -	Reduction in RSP Concentration - Yellow Fibreglass Filter	24
Figure 10 -	Reduction in RSP Concentration - AAA Electrostatic Filter	25
Figure 11 -	Reduction in RSP Concentration - Dynamic Electrostatic Filter	26
Figure 12 -	Reduction in RSP Concentration - Clean AAA Filter	27

LIST OF TABLES

	Page
Table 1 - Baseline Sound Levels (Stock Filter)	13
Table 2 - Sound Level Comparisons	17
Table 3 - Filter Pressure Drop Values	20

LIST OF PHOTOGRAPHS

	Page
Photograph 1 - Coach No. 2157	36
Photograph 2 - Fan Compartment	37
Photograph 3 - Return Air Vent	37
Photograph 4 - Air Filter Compartment	38
Photograph 5 - Sound Level Meter Test Setup	39
Photograph 6 - HVAC Controls	40
Photograph 7 - Test Equipment	41
Photograph 8 - Fiberglass Media Filter Before Testing	42
Photograph 9 - Fiberglass Media Filter After Testing	42
Photograph 10 - Electronic Filter Before Testing	43
Photograph 11 - Electronic Filter - Power Converter and Electrodes	43
Photograph 12 - Electronic Filter - Power Converter and Electrodes	44
Photograph 13 - Washable Polypropylene Filter Before Testing	45
Photograph 14 - Washable Polypropylene Filter After Testing	45

1.0 INTRODUCTION

1.1 Scope

Deluc Corporation, in association with TES Limited and Concord Scientific Corporation, were contracted to investigate problems associated with the climatic control system of intercity coaches. The problems addressed in this study were windshield fogging, sound levels and air quality inside a Prévost Marathon XL Intercity Coach. The objective of these investigations was to gather pertinent information through testing and anaiysis and develop recommendations that could be used to improve passenger comfort in a new model of intercity coach currently under development at Prévost Car.

Shortly after the study work commenced, in June of 1988, it became known that production drawings for the new coach's HVAC system were 70 percent complete, that the duct work associated with the system was in the process of being installed on the prototype bus, and that the HVAC system would be completely finished by mid-July of 1988. These time constraints resulted in the study investigations being very limited with respect to Outdoor Air Quantity and Control and Noise. In-depth investigations could only be pursued in the areas of Windhsield Fogging and Alternative Filter Evaluation.

This work was undertaken as follow-up to an earlier TDC project, "Air Quality Study of Intercity Coaches," conducted in 1987.

1.2 Background

A common problem with intercity buses in late fall and early spring is the build up of fog on the interior of the driver's windshield. The windshield tends to fog-up in the corners, or along the sides. Fogging in these locations makes it very difficult for the driver to use the side mirrors. Windshield fogging is observed primarily when a coach leaves the terminal. After maintenance staff clean and disinfect the coach interior, there is sufficient moisture in the coach to cause

condensation on the inside windshield surface. This, combined with a temperature difference between the coach interior air and the exterior ambient air, causes fogging to occur on the windshield.

In order to develop a strate[illegible]o improve passenger compartment noise reduction and air quality, a testing program was developed to evaluate the climatic control system of the intercity coach. It was felt that improving the filtering ability of the HVAC system would improve air quality. Thus, three alternative 25 mm filters were selected by Prévost for evaluation: a fibreglass filter, a "DYNAMIC" electronic filter and an "AAA" washable polypropylene filter. The filters were tested for their screening abilities. The "DYNAMIC" and "AAA" filters are both electrostatically augmented filters.

Each of the alternative filters varied in their media composition and design. The fibreglass filter tested was a standard throwaway fibreglass media pad held in a custom fabricated frame. The electronic filter consisted of a frame that opens up about a bottom hinge. Inside the frame is a replaceable media pad with a fibreglass-like composition. An electrical box is attached to one side of the filter, where an electric adapter power socket and a neon indicator lamp are located. The washable polypropylene filter consisted of an aluminum frame with flattened expanded aluminum screens on both faces. The filter media consists of several woven sheets of electrostatically charged polypropylene. These three filters were tested against the Prévost stock filter, which consists of a number of layers of coarse stainless steel mesh.

This report presents the results of the various investigations as well as recommendations and conclusions.

2.0 TEST METHODOLOGY

The overall air distribution schematic of the Prévost Marathon XL Intercity Coach is shown in Figure 1. As illustrated in this drawing, the driver and passenger compartment HVAC systems are independent from each other and, as such, were analyzed separately. The driver HVAC system was tested to investigate the problem of driver windshield fogging and the passenger compartment HVAC system was used to evaluate the effect of the alternative filters on air quality.

2.1 Windshield Fogging

The problem of windshield fogging was investigated by measuring the direction and volume of air exiting the defrost diffusers on selected MCI and Prévost coaches. Voyageur Colonial Inc. personnel were also interviewed to obtain information on actual practises. An analysis of both measurements and comments was conducted to determine potential solutions to alleviate the fogging problem. Three of these solutions are discussed in Section 3.1 of the report.

2.2 Alternative Filter Evaluation

The three alternative filters were tested and compared against the Prévost stock filter in terms of filter pressure drop since it is related to the particle removing capability of each filter. In order to determine the screening capabilities and hence the effect on air quality, it will be necessary to compare both the results from the pressure drop measurements with the results from Concord Scientific's particle analyzer. Concord Scientific, an industrial hygiene firm, was responsible for determining the relative effectiveness of each filter. The method used to determine each filter's screening capabilities is presented in Section 2.2.3 and results are presented in Section 3.4.

Photograph 1 shows the vehicle that was used to measure baseline and final pressure drops and sound levels. Figure 2 and Photographs 2 through 4 illustrate

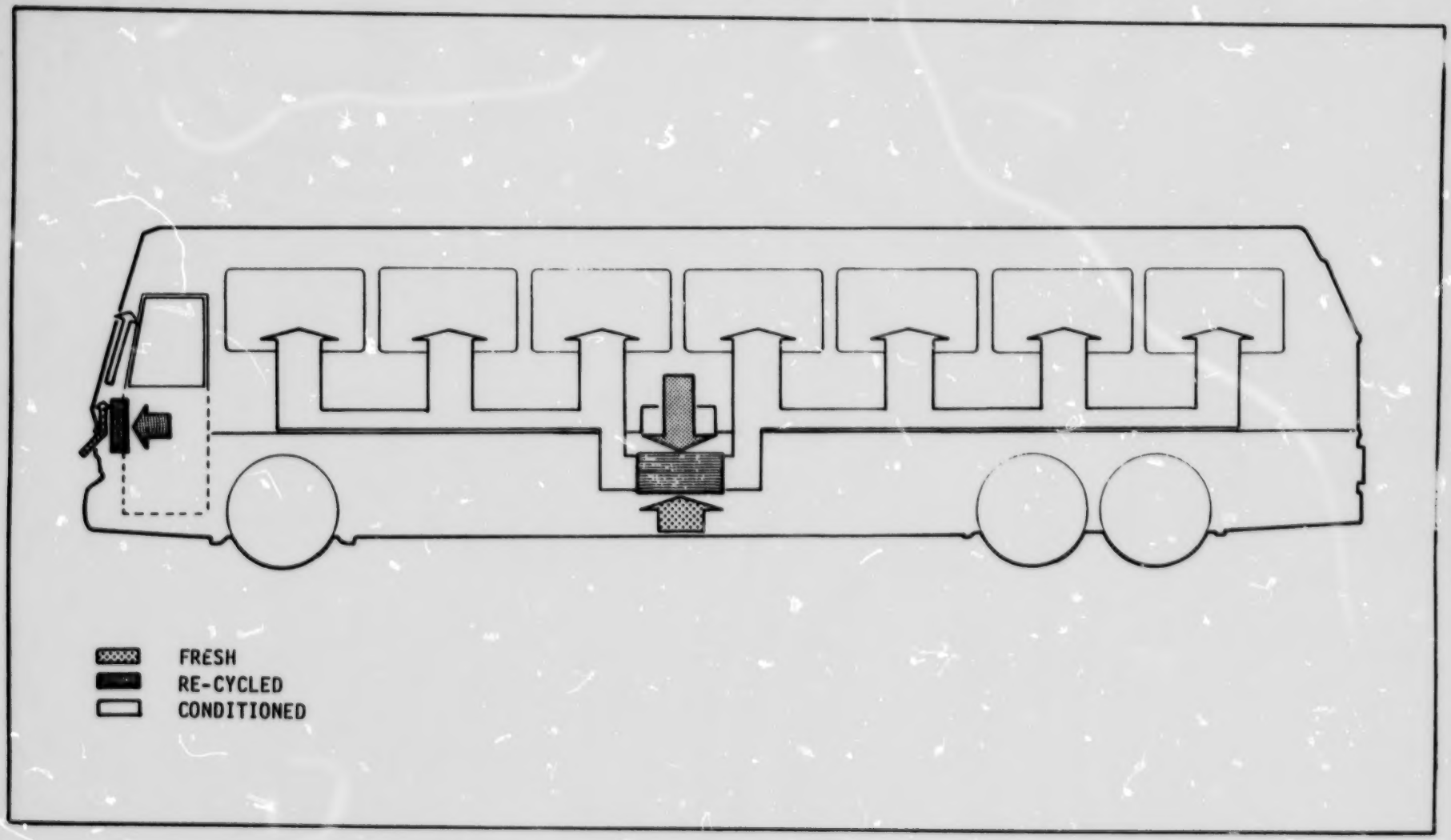


FIGURE 1

AIR DISTRIBUTION SCHEMATIC - MARATHON XL INTERCITY COACH

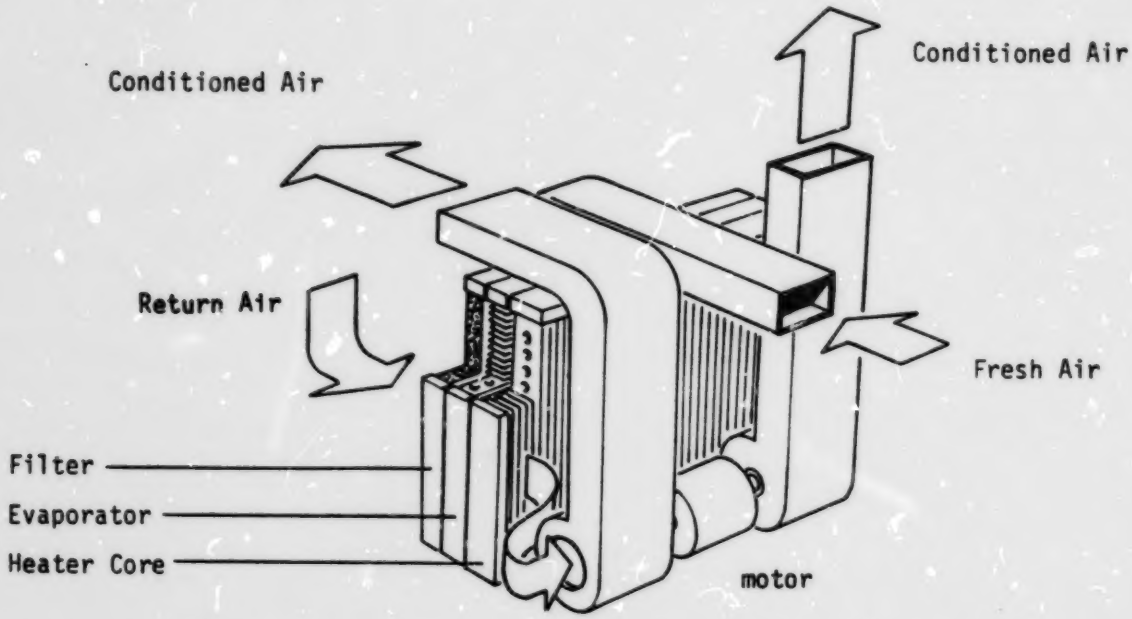


FIGURE 2

PLENUM DETAIL - MARATHON XL INTERCITY COACH

the passenger compartment HVAC system. Air enters the filter compartment through the return air vent and passes through the filter, evaporator and heater core where it is returned as "conditioned air" into the passenger compartment.

2.2.1 Sound Level Measurements

The equipment used to measure the sound levels in the test vehicle is shown in Photograph 5. Sound level measurements were taken at three locations for each seat number (see Figure 3) at a height of 41" from the floor (approximate ear height of a seated passenger of average size). The three measurement locations were referenced from the window and are as follows:

AT WINDOW:	2" from window
MIDDLE OF SEAT:	16" from window
AT AISLE:	34" from window

For these tests the passenger compartment HVAC system controls (shown in Photograph 6) were set to full air conditioning (lowest temperature selected), and the fan was set to "ON". All roof vents, windows and doors were closed. The driver HVAC system was not operated during the sound level testing. For convenience, the sound levels were measured while the test vehicle was parked in neutral with the engine set to fast idle. No allowance was made for the noise attenuation caused by the presence of passengers.

2.2.2 Pressure Drop Measurements

Four Marathon XL Intercity coaches were obtained to evaluate the three alternative filters against the Prévost stock filter. In order to ensure consistent results, one of these coaches (No. 2157) was used for all baseline and final measurements. All four filters were installed (one at a time) in the passenger compartment HVAC system of coach No. 2157 and initial pressure drop measurements were made. A digital manometer and pitot static probe tube, shown in Photograph 7, were used to obtain the pressure drops across the various

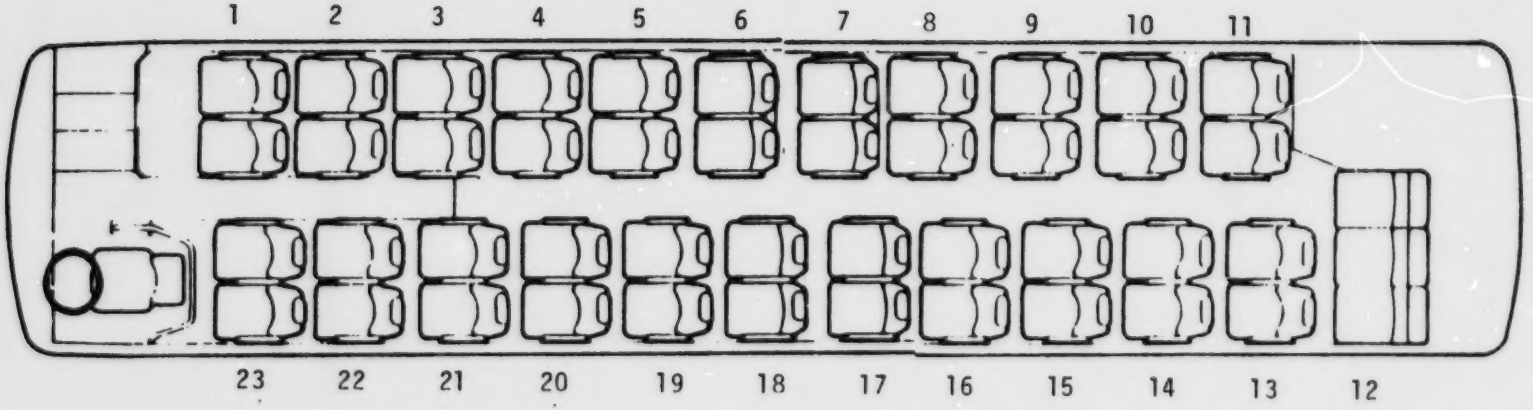


FIGURE 3

SEAT NUMBER SCHEME - MARATHON XL INTERCITY COACH

filter/evaporator/core combinations. It was assumed that any change in the condition of the evaporator and core in the test vehicle would affect all four filter pressure drop measurements in the same manner.

In order to measure the pressure difference across the filter/evaporator/core combination, two access holes were drilled, into which the pitot static probe tube was inserted. One hole was drilled through the filter service door and another was drilled through the separating wall between the baggage compartment and the fan/motor compartment. During baseline and final testing, the passenger compartment HVAC system controls on coach No. 2157 were, again, set to full air conditioning and the fan set to "ON". All roof vents, doors and windows were closed and the fresh air damper was set to full open.

Following its initial pressure drop measurement, each filter (Prévost stock, fibreglass and washable polypropylene) was removed from coach No. 2157 and installed in the passenger compartment HVAC system of one of three designated Marathon XL Intercity coaches. The electronic filter remained in coach No. 2157 since it required electrical connections.

Modifications to the filter restraint channels were necessary to accommodate the difference in size and thickness of the trial filters. The Prévost stock filter was approximately 3/4" thick, while the alternative filters were only available in the 1" nominal industry standard thickness. As well, the width and length of the alternative filters differed from the Prévost stock filter. Any gaps were sealed using duct tape and a correction factor for the true filter area (detailed in Section 3.3) was used to calculate the pressure drop results.

Four coaches were used simultaneously to test the filters, because of the time restriction imposed on the program schedule. These four Marathon XL Intercity coaches were then operated on similar routes for three weeks. The distance that each coach travelled with the alternative filter installed, was recorded and incorporated into a correction formula (detailed in Section 3.3) used to determine the pressure drop across the filter.

Following the three week test period, the Prévost stock, fibreglass and washable polypropylene filters were removed and reinstalled into coach No. 2157 (one at a time) for final pressure drop measurements. The electronic filter was, of course, already installed in coach No. 2157 and the final pressure drop across it was also measured.

2.2.3 Respirable Particulate Removal Measurements

The objective of the work was to test the comparative efficiencies of several filter media in their abilities to remove respirable suspended particulate (RSP) from air in an inter-city bus.

The general principle of the test procedure was to increase the concentration of smoke in an unoccupied and stationary bus, and to track the reduction of smoke concentrations over time, with the engine and ventilation system running. The procedure was repeated with each test filter mounted in the HVAC system.

Testing was done using new filters, and was repeated with similar filter types after they had received normal use. Four filter types were designated for use:

1. Stock bus filter;
2. Yellow fibreglass filter;
3. AAA Electrostatic filter (washable polypropylene); and
4. Dynamic electrostatic filter (electronic).

The three alternates to the stock bus filter were selected by Prévost largely because they are compact, that is, all nominally 25 mm filters, and offer little resistance to flow or small pressure drops. The choice also sought to compare washable filters (Prévost stock and "AAA" electrostatic) with disposable filters (yellow fibreglass and "Dynamic" electrostatic). Available supplier data and standard ASHRAE test results are included in Appendix A and B.

A smoke source was required which would provide large and similar quantities of smoke over a short period of time, so that an equivalent start point for each

test run could be achieved. The smoke source selected for the work was a smoke bomb (Superior Signal Inc., #3C), containing hydrated zinc chloride. Therefore, the smoke products were zinc chloride fume, zinc oxide, and hydrogen chloride.

At the beginning of each test run, the bus engine was turned off and the test filter was put into place. Then a smoke bomb was placed in an incombustible holder on the floor at the centre of the bus, where it was ignited and allowed to burn down (three minutes). During this time, the observer remained outside the bus, the door was shut, and the bus engine remained off.

After combustion was complete, the observer entered the bus, closed the door, and started the bus engine. Another 8-10 minutes were then allowed for the ventilation system to assist mixing and dispersing the smoke throughout the bus.

Smoke concentrations were measured using a digital dust monitor (Sibata Model P-5). This is an electro-optical instrument, which measures concentrations of airborne respirable particulate by determining the change in light, from a fixed intensity beam, caused by the aspirated dust. The instrument was placed on an aisle seat (row 6, driver side) over the air return. The instrument was raised so that its intake was 15" above the seat.

One minute measurements were recorded from concentrations of 2700 counts per minute (cpm) until readings returned close to background level. Then, the procedure was repeated with the next test filter.

3.0 RESULTS

This section summarizes the results of the windshield fogging and alternative filter evaluations.

3.1 Windshield Fogging

In order to investigate the fogging problem, the direction and volume flow of the air exiting the defrost diffusers were measured on two MCI and two Prévost coaches. The results showed that approximately seven percent of the air flow on the MCI coach, and approximately nineteen percent on the Prévost coach, is directed into the corners of the windshield. These results support the different degrees of fogging noted by Voyageur personnel on the two coach types (i.e., more flow, less fogging).

There are several alternative solutions for reducing the severity of windshield fogging. The first alternative would be to divert more air into the corners of the windshield. Although this would reduce the fogging in the corners, it may shift the fogging problem to the centre of the windshield since there would be less air flow in the centre area.

A second alternative would be to increase the overall flow through the driver HVAC system. This again would reduce the fogging in the corners but may also create new problems. For example, there are areas in the front of the bus which are close to the sound comfort threshold. An increase in flow may result in sound levels that would exceed this threshold.

A third alternative would be to install directional fans at the bottom corners of the windshield. These would be independent of the existing driver HVAC system. These fans would be installed in locations that would not impede the driver's view. The overall cost to install such fans would be less than to modify the existing driver HVAC system ducting. The fan mounts would be adjustable to allow for variations in coach models and environmental conditions. Although this

alternative would result in slightly increased sound levels in the front of the bus, the increase would be less than the second alternative.

The third alternative outlined above was actually implemented in an articulated bus and the problem of windshield fogging was greatly reduced. This alternative appears to be the most attractive method to reduce the severity of the driver windshield fogging.

3.2 Sound Level Measurements

Using the seat number scheme shown in Figure 3, sound levels were recorded at the three locations for every seat (numbers 1 through 23) with the Prévost stock filter installed. These results are shown in Table 1 and in Figures 4 and 5. These results show sound level peaks in the middle of the bus (caused by the fan motor) and at the rear (caused by the coach engine). The highest sound levels recorded in the vehicle occurred in seats 6 and 17, where the sound levels exceeded 75 dB at the window seats. According to the Occupational Health and Safety Act, the maximum sound level permissable for exposure eight hours a day, is 90 dB. However, the CRC Handbook defines 55 dB as the background sound level at which conversation becomes unintelligible.

The sound measured in the middle of the coach contained a constant frequency component that decreased substantially when the passenger compartment HVAC fan was switched off. The sound levels measured at the rear were not influenced by the passenger compartment HVAC fan, however, the sound levels significantly decreased as the engine was switched from high to low idle. Note that the latter sound level peak contained a low frequency component unique to this group of seats.

Subsequent to the general study of the sound levels with the Prévost stock filter installed, the sound level was again measured at the middle location at selected

SEAT NUMBER	AT WINDOW [dB]	AT MIDDLE [dB]	AT AISLE [dB]
1	67.0	64.0	65.0
2	66.0	64.5	66.0
3	68.0	67.0	67.2
4	69.5	68.5	68.0
5	74.2	70.8	69.5
6	75.4	74.5	72.8
7	73.2	71.8	70.2
8	70.8	69.5	69.2
9	71.0	69.2	69.0
10	71.8	69.6	68.8
11	72.8	71.2	70.6
12	72.6	71.2	70.6
13	74.5	74.0	71.0
14	72.2	70.5	69.8
15	71.8	70.5	69.2
16	73.2	71.2	70.2
17	75.2	72.8	71.2
18	75.0	73.5	72.0
19	71.8	70.0	69.2
20	69.5	68.0	68.2
21	68.8	66.2	67.2
22	67.8	66.2	66.2
23	66.8	65.8	64.8

TABLE 1

BASELINE SOUND LEVELS (Stock Filter)

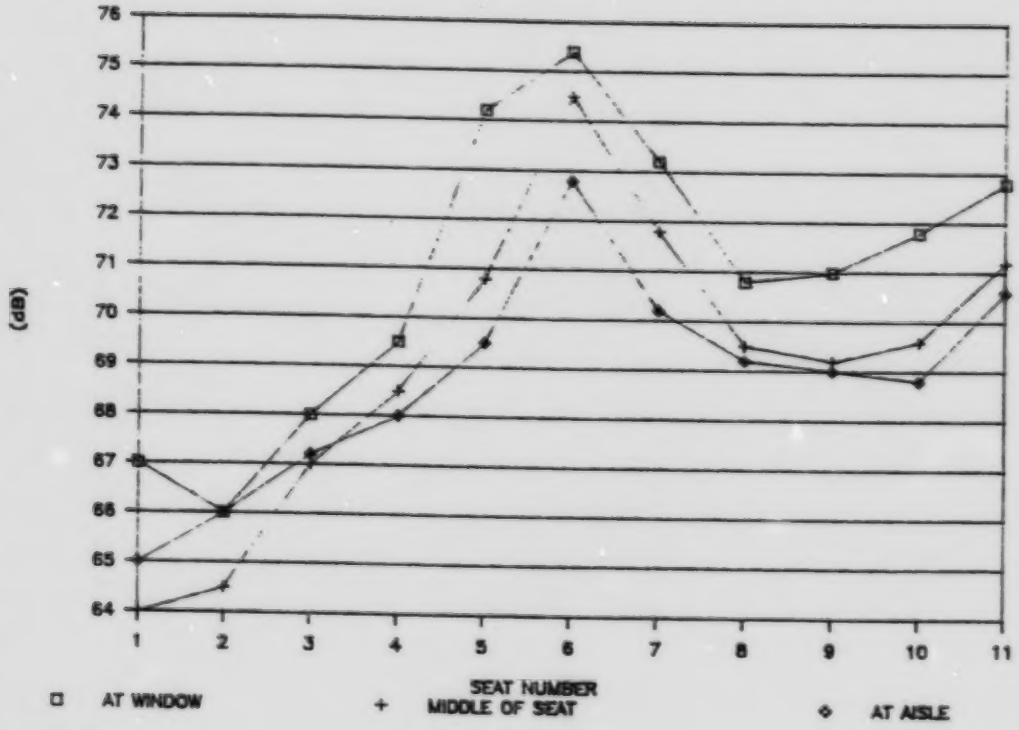


FIGURE 4

MEASURED SOUND LEVELS - RIGHT SIDE

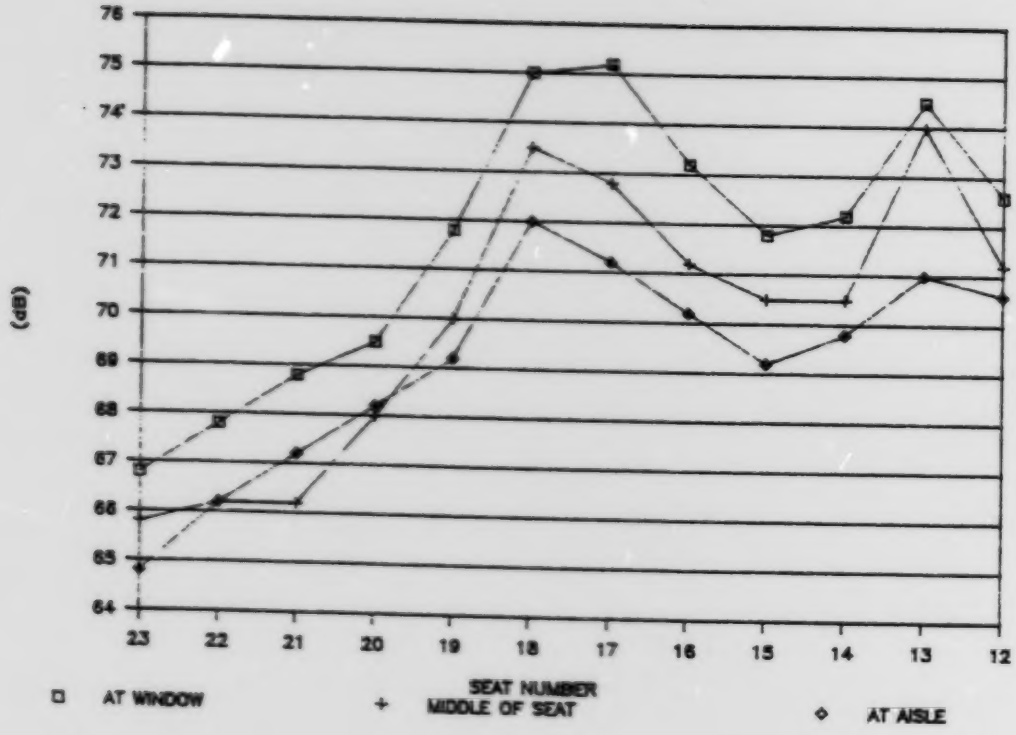


FIGURE 5

MEASURED SOUND LEVELS - LEFT SIDE

seats with each of the three trial filters installed. In most cases the trial filters appeared to slightly reduce the sound level. A general trend was observed that indicated that the sound levels decreased towards the aisle of the coach. These measurements are contained in Table 2. Included in this table are the measurements obtained with the Prévost stock filter for comparison.

The differential sound levels for each of the three trial filters, as compared to the Prévost stock filter, are shown in Figure 6. From the graph, it can be seen that the replacement filters reduce the sound level at given seat locations by varying degrees. It appears that the fibreglass filter resulted in the greatest sound reduction overall, followed by the electronic filter and then the washable polypropylene filter. Note, however, that the noise reduction measured with the alternative filters installed was not large. The reduction varied from 0.25 dB to 3.75 dB and would be the result of two compounding factors. The first being less fan noise sound transmission through the return air system owing to the improved sound deadening characteristics of the alternate filters. The second being less air flow and hence reduced noise at the supply diffuser because of the increased pressure drop associated with the alternate filters.

3.3 Pressure Drop Measurements

Due to route scheduling, it was not possible to have all four road vehicles travel identical distances. To compensate for this, the mileage travelled was recorded and used in conjunction with the filter area to apply a correction factor which normalized the pressure drop results. To calculate the increase in pressure drop, the following procedure was used. The initial pressure drop was measured and this value subtracted from the measured final pressure drop. A correction factor was then applied to the increase in pressure drop to allow for differences in filter flow area and mileage. For example, the fibreglass filter was measured to have an increase in pressure drop of 20.2 Pa. Using the correction formula:

SEAT NUMBER	Middle Position Sound Levels (dB)			
	STOCK FILTER	FIBERGLASS FILTER	ELECTRONIC FILTER	WASHABLE POLYPROPYLENE FILTER
2	64.5	64.8	62.2	65.2
4	68.5	66.8	67.5	67.8
6	74.5	73.0	72.2	74.2
8	69.5	68.0	67.5	69.5
10	69.6	66.5	67.6	68.0
14	70.5	68.4	68.8	69.5
16	71.2	67.4	69.5	70.2
18	73.5	71.2	72.2	71.5
20	68.0	66.5	67.5	67.0
22	66.2	64.8	65.0	65.4

TABLE 2

SOUND LEVEL COMPARISONS

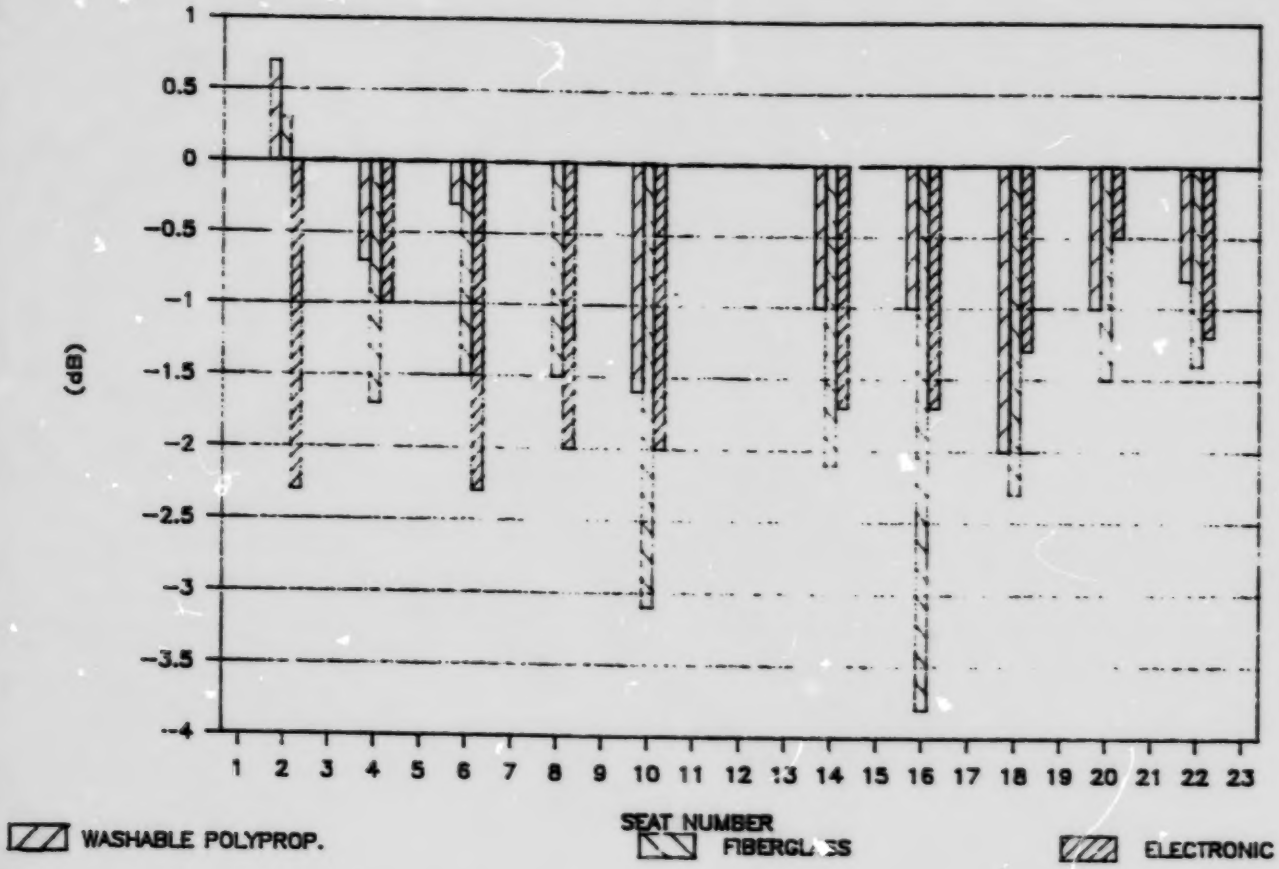


FIGURE 6

DIFFERENTIAL SOUND LEVELS

$$\text{Corrected Increase in Pressure Drop} = \text{Actual Increase in Pressure Drop} \times \frac{\text{Flow Area}^2}{\text{Filter Size}^2} \times \frac{\text{Furthest Distance Travelled}}{\text{Actual Distance Travelled}}$$

$$= 20.2 \times \frac{4117^2}{4644^2} \times \frac{9265}{5081}$$

$$= 32.3 \text{ Pa}$$

Thus the corrected increase in pressure drop was calculated to be 32.3 Pa.

These results are shown in Table 3. The increases in pressure drop are shown on Figure 7. The filter that showed the highest change in pressure drop was the electronic filter. The Prévost stock filter showed the lowest change in pressure drop.

Pre-test and post-test photographs (Photographs 8 through 14) were taken of each filter. The discolouration of the fibreglass filter did not appear uniform and seemed to be concentrated around the restraint wires. The discolouration on the electronic filter, however, was quite uniform with the exception of a local concentration in the electrode/media interface location. The washable polypropylene filter was discoloured uniformly through the filter, with most of the contaminants trapped on the upstream surface.

From the results it is clear that the various filters act differently in removing contaminants from the air. The merits of each filter, based on pressure drops, sound levels and economic considerations, are discussed in detail in Section 5.0 of this report.

3.4 Respirable Particulate Removal Measurements

The results in counts per minute (cpm) were plotted over time, and are given in Figures 8 through 11, for the four different filter types, clean (unused), and dirty (used).

FILTER TYPE	INITIAL ΔP [Pa]	FINAL ΔP [Pa]	ACTUAL INCREASE IN ΔP [Pa]	FILTER AREA [cm]2	DISTANCE TRAVELLED [km]	CORRECTION FACTOR	CORRECTED INCREASE IN ΔP [Pa]
Stock	106.8	124.7	17.9	4644	5905	1.57	28.1
Fiberglass	113.4	133.6	20.2	4117	5081	1.43	28.9
Electronic	135.4	163.8	28.4	3997	6117	1.12	31.9
Washable Polypropylene	127.0	164.5	37.5	4117	9265	0.79	29.5

TABLE 3

FILTER PRESSURE DROP VALUES

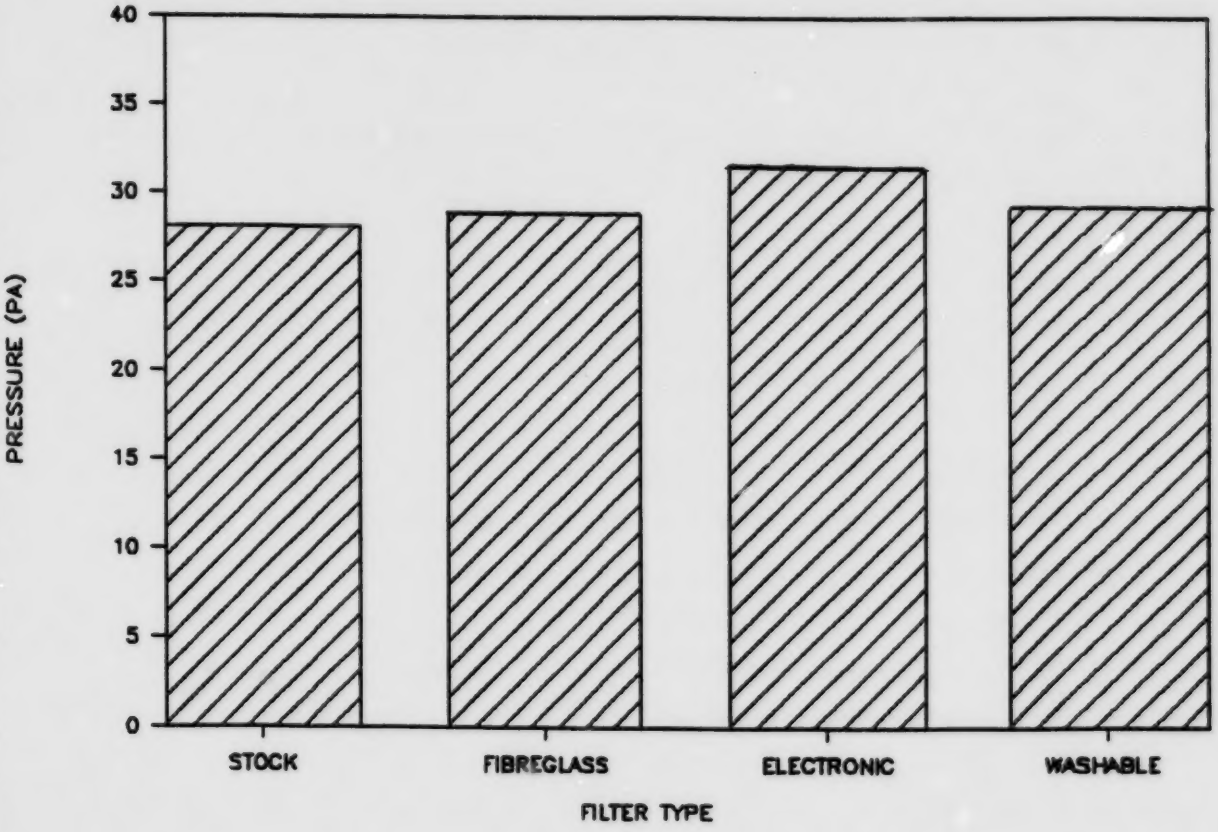


FIGURE 7

CORRECTED PRESSURE DROP INCREASE

The procedure was repeated with a clean AAA electrostatic filter and cigarette smoke, as well as with a smoke bomb, in order to compare the effects of the different smoke source. Large concentrations of cigarette smoke were generated using a bee-keepers smoker and cut tobacco. The results in cpm from the two runs were plotted over the same concentration range over time.

Figures 8 through 11 illustrate the improved filtration efficiency of dirty (used) filters over clean (unused) filters. With all used filters, the time required to reduce RSP concentrations from 2700 cpm to background levels was ten (10) minutes less than when the filters were new.

There are fewer noticeable differences among the four new filters in their abilities to remove RSP. Each reduces the RSP concentrations from 2700 cpm to background range over a thirty (30) minute period. RSP reduction to 500 cpm was slightly faster with the yellow fibreglass filter (approximately 17 minutes) than with any other (approximately 19 minutes). From these results, it appears that the electrostatic removal processes associated with two of the test filters are not operating effectively or that the non-electrostatically augmented filters were benefiting from a significant bus movement induced charge of static electricity. The concentrated soiling near the restraint wires on Photograph 9 is evidence that seems to confirm the significance of the ambient charge of static electricity.

The variability in the curves at 7-12 minutes suggest uneven dispersal of the smoke. As similar variations occur in all runs with all filters, they may be due to characteristics of the ventilation system rather than characteristics of the filters.

Figure 12 illustrates the comparative efficiency of a clean AAA electrostatic filter in the removal of cigarette smoke and smoke bomb smoke. The RSP concentration after a ten minute period from 1335 cpm was 255 cpm (smoke bomb) and 186 cpm (cigarette smoke); RSP reduction from 1300 cpm to 200 cpm occurred in 10 minutes for cigarette smoke, and 13 minutes for smoke bomb smoke. These differences may not be significant, or they may suggest a slight improvement in removal of cigarette smoke over smoke bomb smoke.

Figure 8 Reduction in RSP Concentration

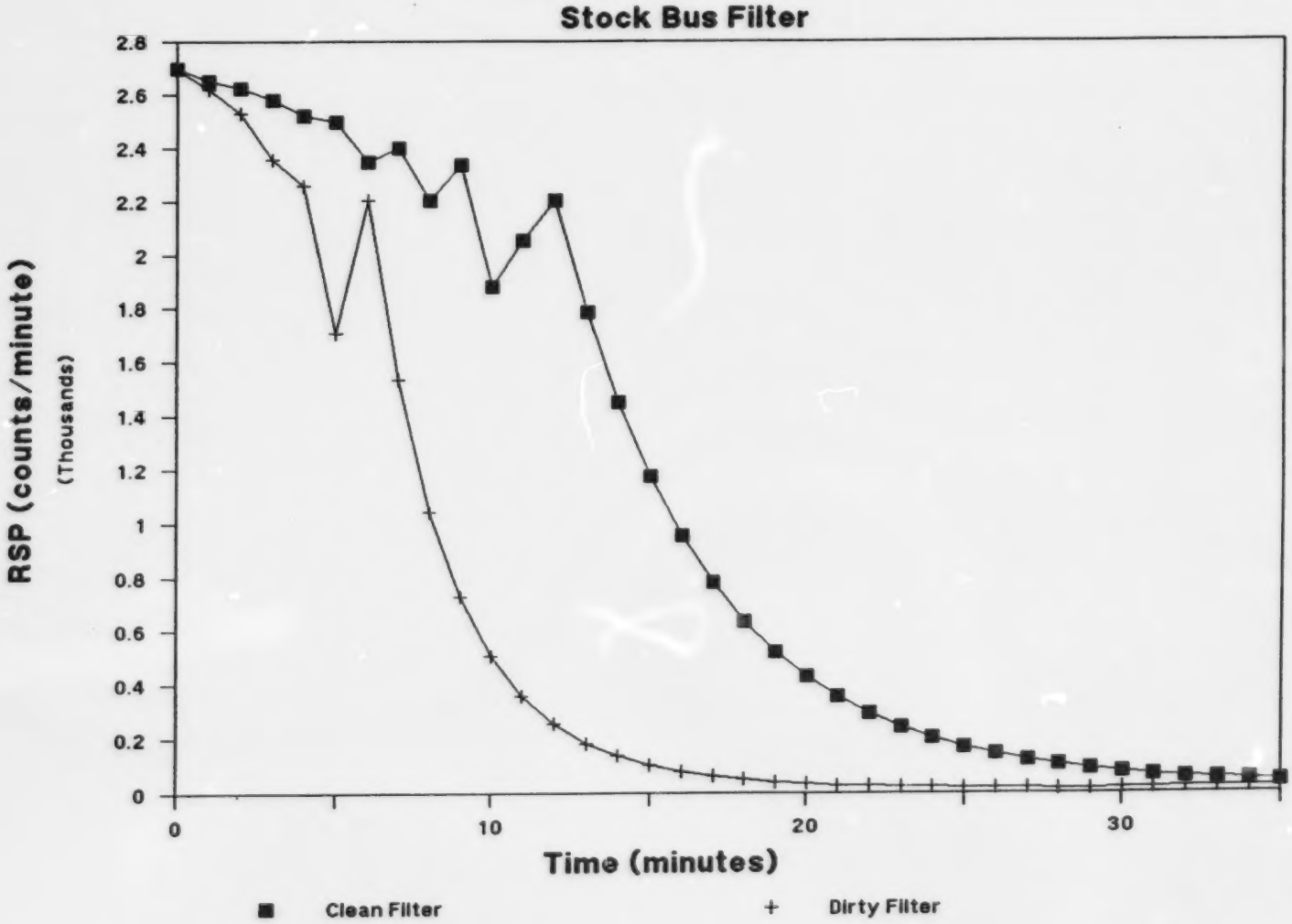


Figure 9 Reduction in RSP Concentration

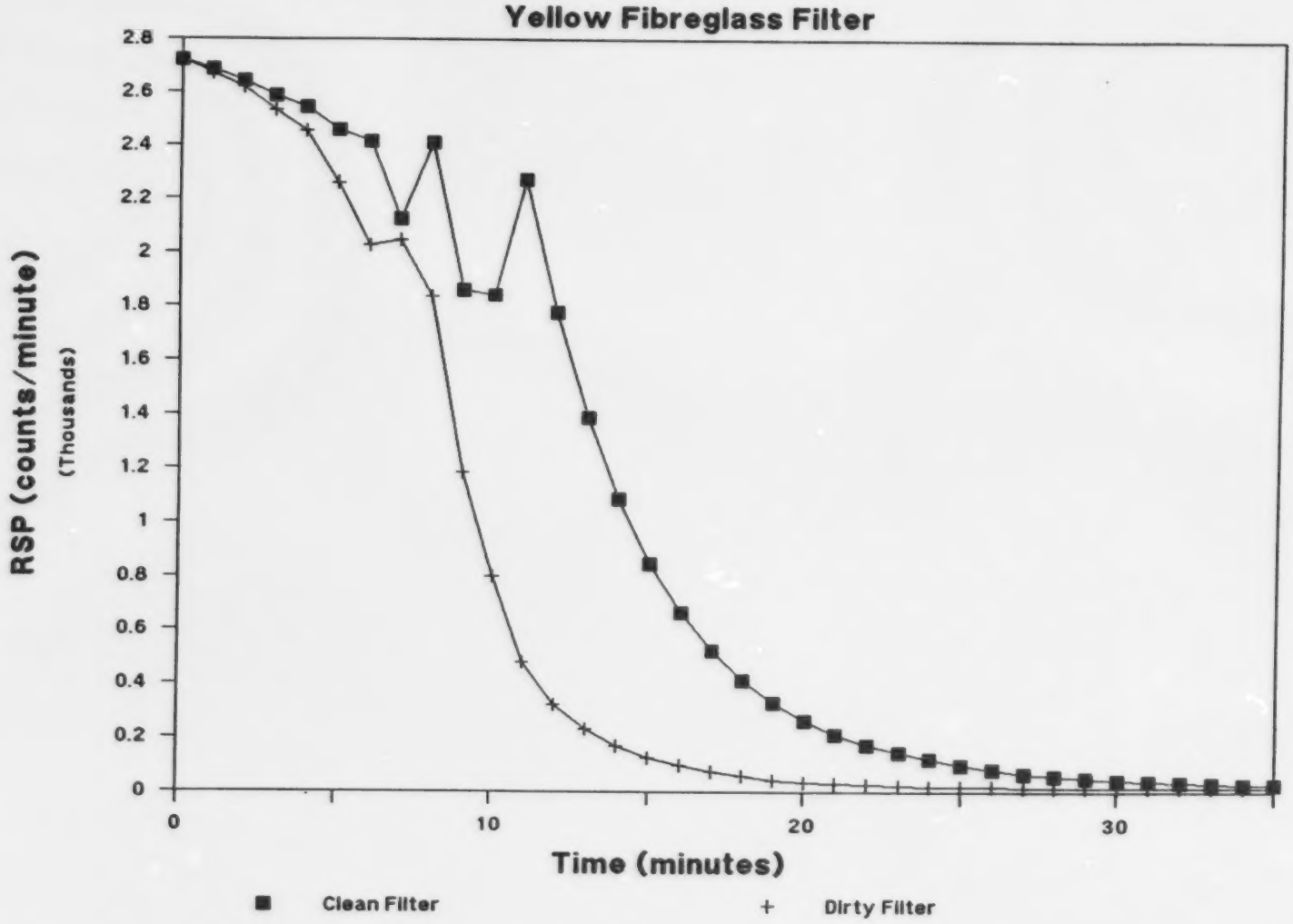


Figure 10 Reduction in RSP Concentration

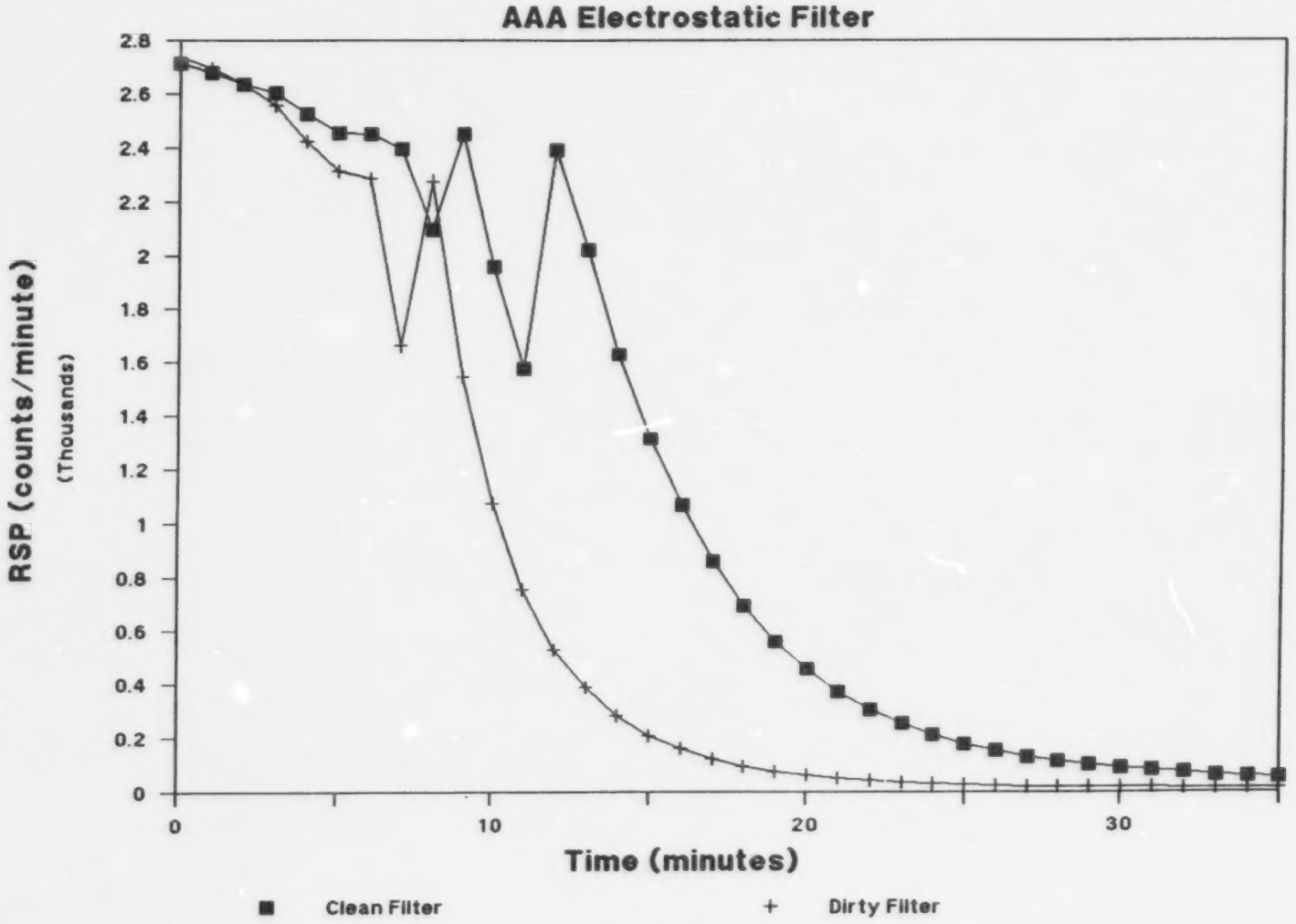


Figure 11 Reduction in RSP Concentration

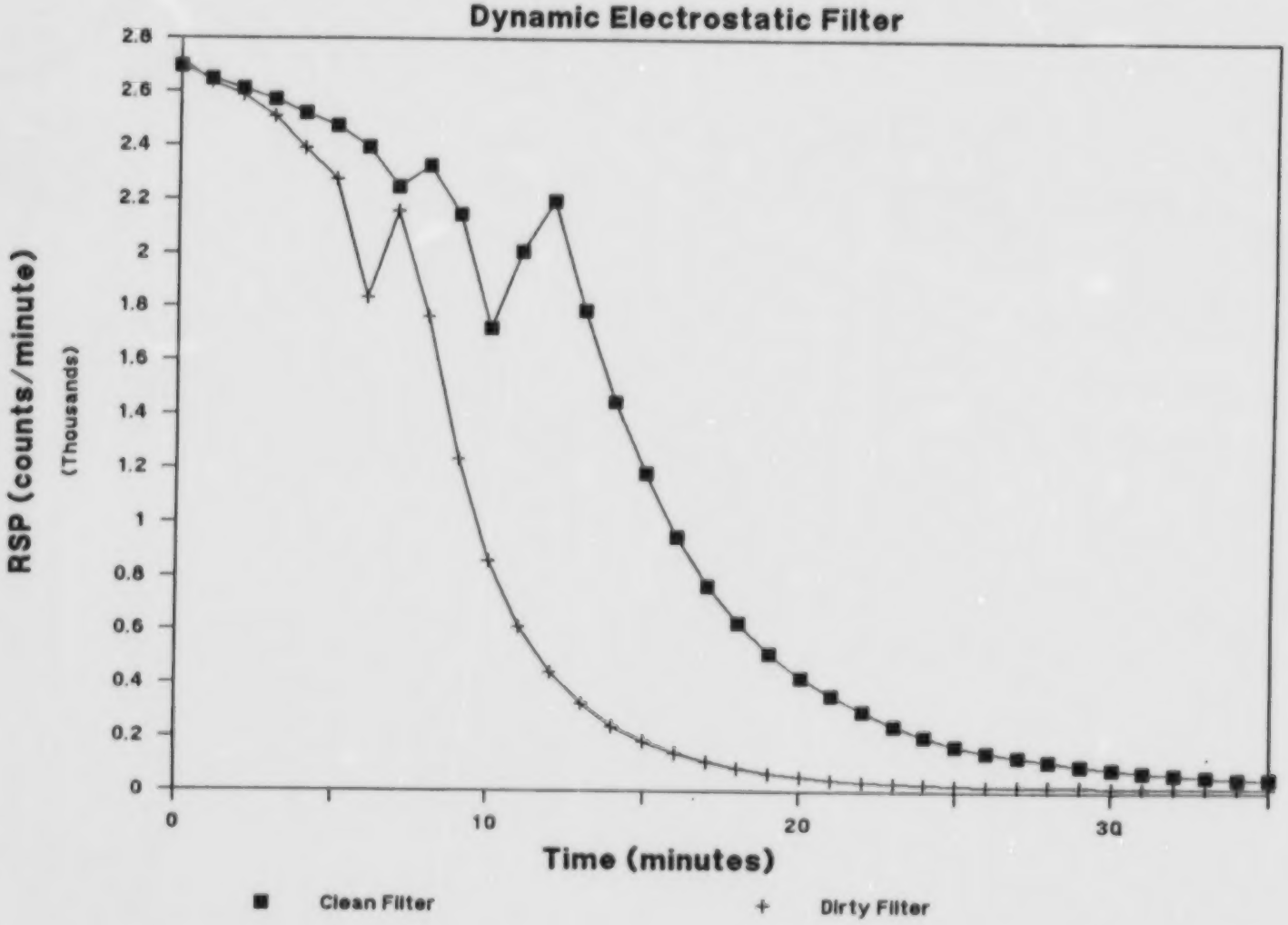
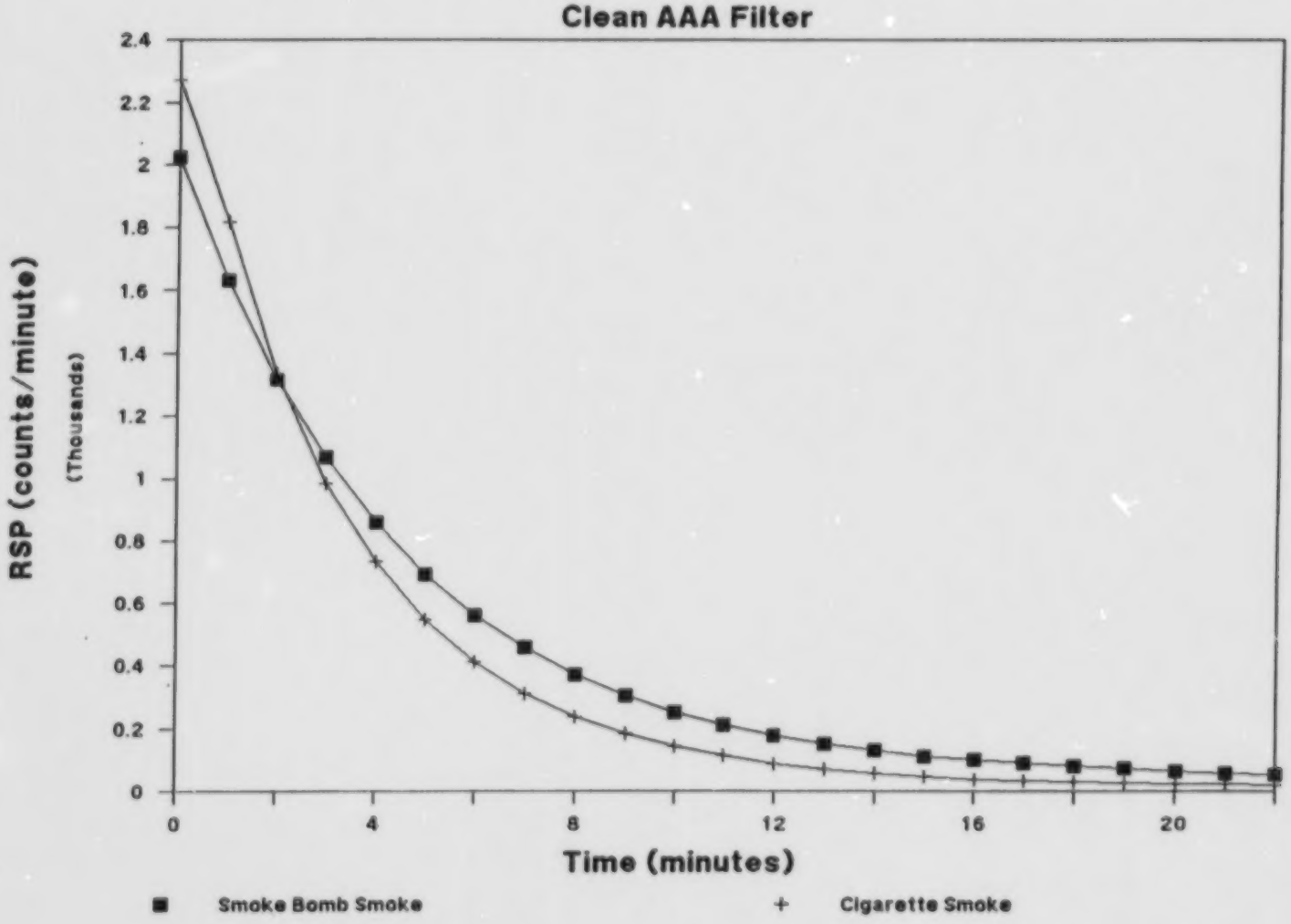


Figure 12 Reduction in RSP Concentration



4.0 ECONOMIC ANALYSIS

There are a number of factors to be considered in determining the cost effectiveness of replacing the stock filter with one of the alternative filters. The factors that should be addressed are as follows:

- initial purchase price of the air filter,
- filter media and filter frame replacement cost,
- manpower requirement for proper maintenance of the air filters,
- modifications to coaches to retrofit the existing fleet, and
- the cost incurred to discard a complete inventory of filters in order to implement a new filter.

These five factors all have an impact on the cost effectiveness of a particular air filter, regardless of its ability to remove air contaminants. To determine the cost effectiveness of each, an economic analysis was conducted.

It has been assumed that the cost to modify the air filter compartment in the coaches, to incorporate a new air filter, would not be significant. It has also been assumed that it would take approximately the same amount of time to wash a washable filter as it would to replace a throwaway filter. Finally, it has been assumed that the labour costs incurred to replace the existing filter inventory with new filters would be constant for all the alternatives.

The two criteria then, that will be used to determine the cost effectiveness of each alternative, will be its initial cost and replacement cost.

The fibreglass filter can be obtained commercially as a complete throwaway unit with a cardboard frame or it can be obtained with a reusable frame and a replacement media. Due to moisture from the evaporator coil, which is located adjacent to the air filter compartment, it was felt that the cardboard frame would not be durable enough. Thus, for the purposes of this cost analysis, a reusable

filter frame was chosen. The filter frame is valued at $40.00 and the filter media refill is valued at $3.00/unit. Assuming a frame life of 10 years and a media service life of 3 months, the following calculation yields an annual cost of $16/year.

$$\text{Annual Cost} = \frac{\text{Frame Cost}}{\text{Frame Life}} + \text{Media Cost} \times \frac{1\ \text{Year}}{\text{Media Service Life}}$$

$$= \frac{\$40}{10\ \text{years}} + \frac{\$3}{\text{filter}} \times \frac{12\ \text{months}}{\text{year}} \times \frac{1\ \text{filter}}{3\ \text{months}}$$

$$= \$4 + 4\,(3) = \$16$$

The electronic air filter consists of a metal screen frame with a replaceable media pad. The unit, if purchased in quantities over 25, costs $70.00, with a replacement filter media cost of approximately $3.00 each. An electrical connection to supply 12 V DC from the bus to the filter is required and has been estimated at a cost of $30.00. Using the same frame life and media service life as in the previous example, the annual cost is $22/year.

The polypropylene filter is a washable filter that has the highest purchase price of those tested. The manufacturer provides a 10 year prorata warranty. With a purchase price of $230.00 and a 10 year life span, the annual cost is $23/year.

The stock Prévost filter is also a washable filter and is valued at $80.00. Based on a frame and media life of ten years, the annual cost is $8/year.

Currently, Ottawa Voyageur Colonial Inc., with a fleet of 150 buses, replaces approximately five to ten filters annually. Because of this low replacement rate, the capital costs associated with the filters are quite low. The trial filters have a less durable frame than the stock filters and as such would require replacement more frequently. It is apparent that even if the replacement lives were equal, the stock filter would be the most economic. Using the previous example, the annual

cost for each filter type is as follows (assuming a 10% interest rate and a 4% inflation rate):

Filter	Annual Cost
Prévost Stock Filter	$ 8.00
Fibreglass Filter	$12.48
Electronic Filter	$17.16
Polypropylene Filter	$23.00

From a strictly economic viewpoint, it would not be feasible to replace the existing stock filter with any of the three trial filters. However, as was stated earlier, this economic analysis does not take into account the effectiveness of the alternative filters in removing particulate from the air. These factors are discussed in Section 5.0.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the windshield fogging investigation and from the evaluation of the alternative filter performance, the following conclusions can be made:

- An increase in the volume of air flow directed to the front corners of the driver's windshield is required to reduce fogging.

- The alternative filters are more effective at reducing sound levels than the Prévost stock filter but this reduction is not significant.

- The washable polypropylene filter and the electronic filter both demonstrated the largest change in pressure drop over time. This indicates that these filters are the most effective at removing particles from the air.

- The Prévost stock filter demonstrated the lowest change in pressure drop over time.

- From a costing viewpoint (i.e., initial purchase price, filter service life, media and replacement cost and frequency of replacement), the Prévost stock filter is the most economic filter among the filters tested.

- No significant differences were observed in the abilities of four (4) filter types to remove RSP. It appears that the principle removal mechanism involved is impaction, as no beneficial effects were noted with the filters with electrostatic removal properties. Or conversely, that the ambient charge of static electricity present on a coach largely defeats the purposeful charge of static electricity associated with the electronic and washable polypropylene filters.

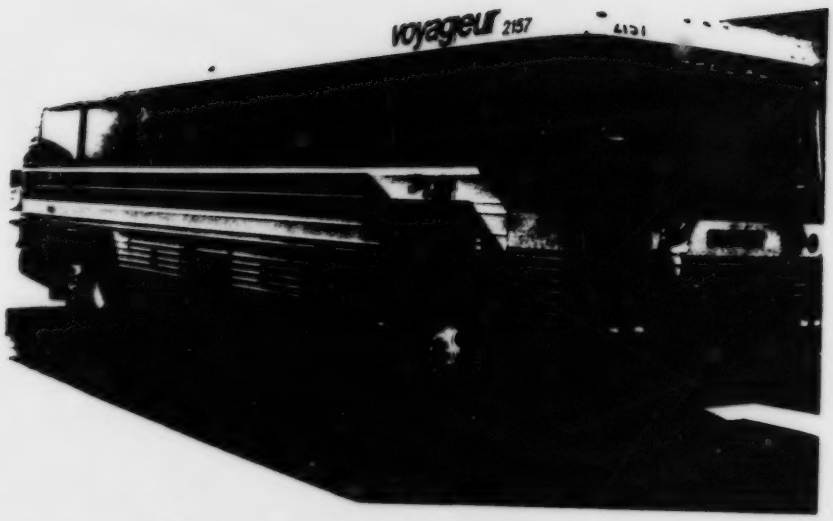
- Improved air quality in buses, through improved removal of RSP, will require alternative approaches, such as increased fresh air makeup.

It is recommended that:

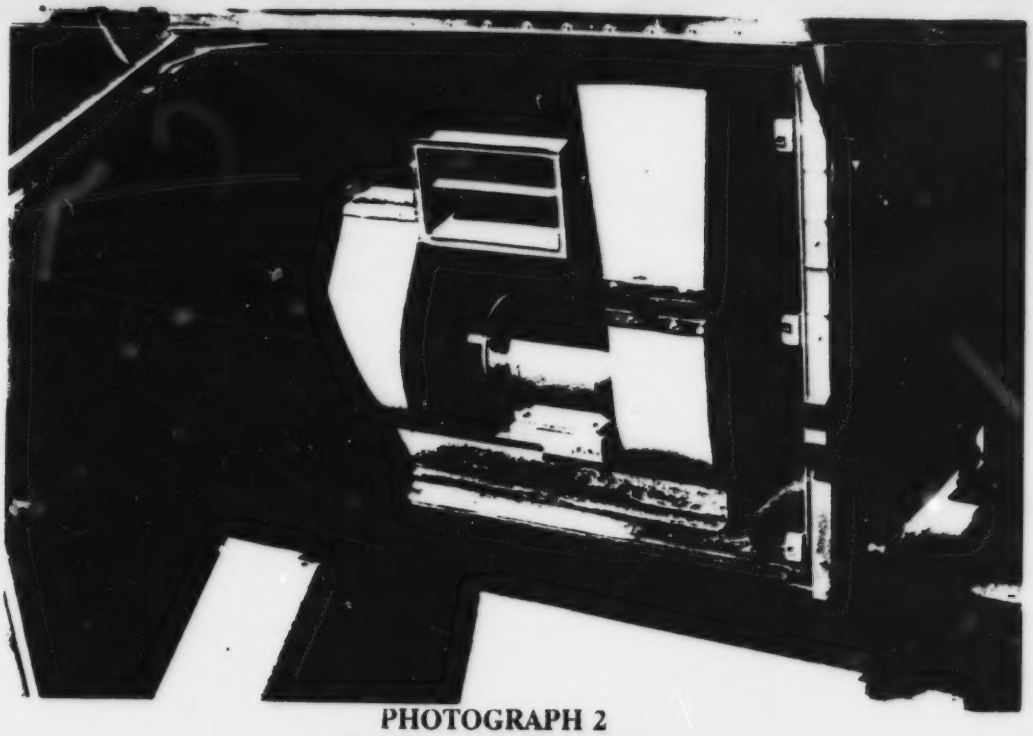
- Independent corner fans be installed to reduce the severity of windshield fogging.

- Filter selection criteria should emphasize airflow considerations, cost, and replacement frequencies if the space criterion remains a high priority. If more space could be made available, more effective filtration technology could be applied.

PHOTOGRAPHS

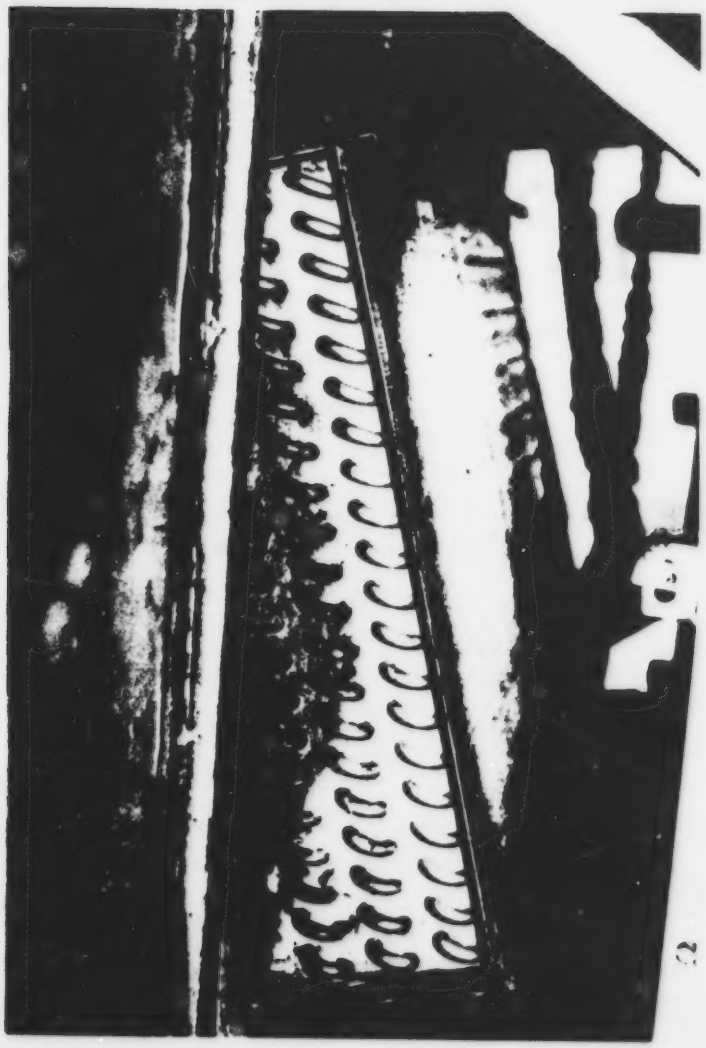


PHOTOGRAPH 1
COACH NO. 2157



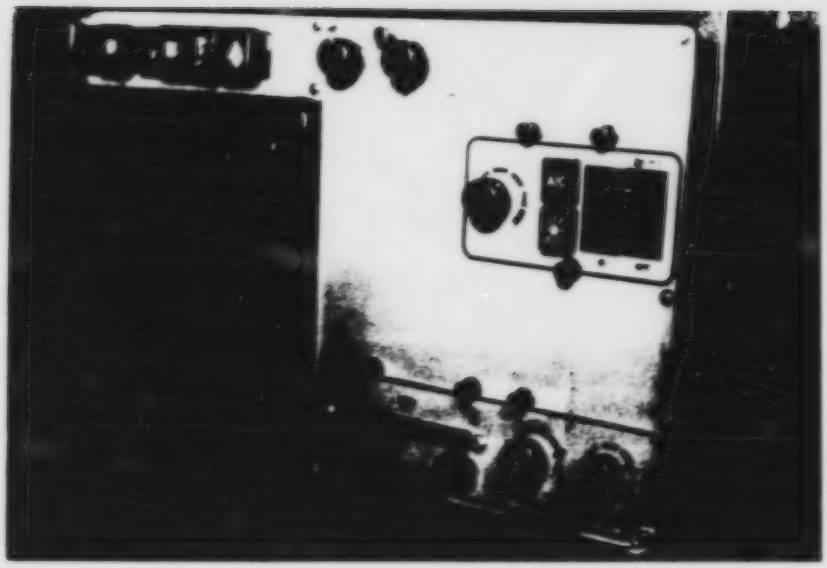
PHOTOGRAPH 2
FAN COMPARTMENT

PHOTOGRAPH 3
RETURN AIR VENT

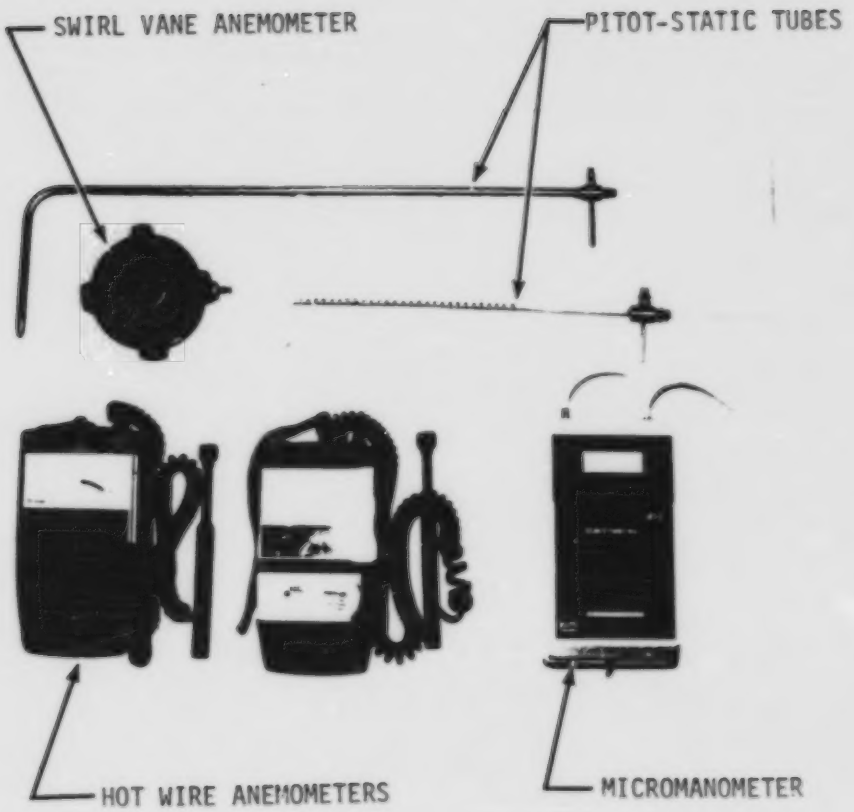


PHOTOGRAPH 4
AIR FILTER COMPARTMENT

PHOTOGRAPH 5
SOUND LEVEL METER TEST SETUP

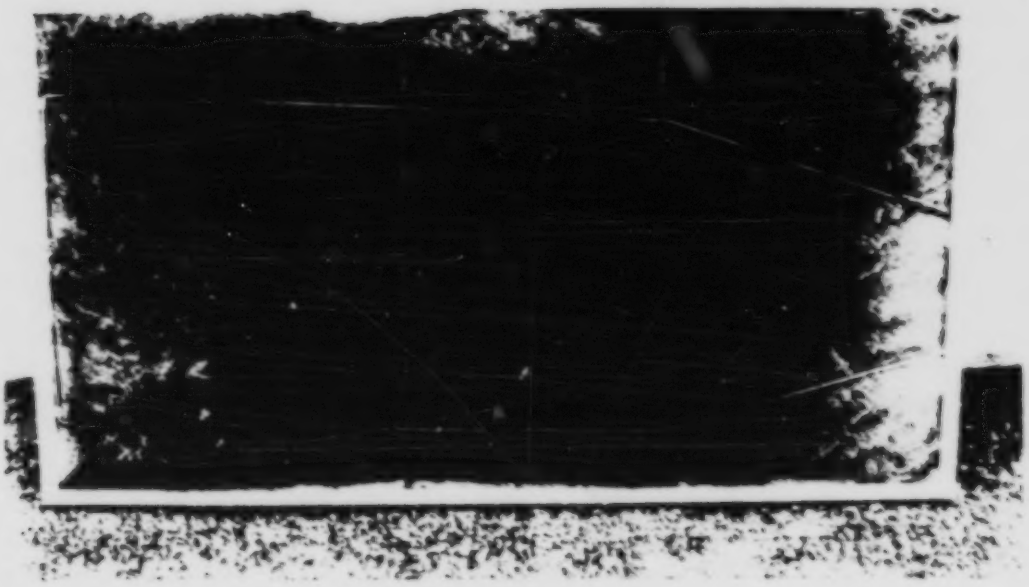


PHOTOGRAPH 6
HVAC CONTROLS

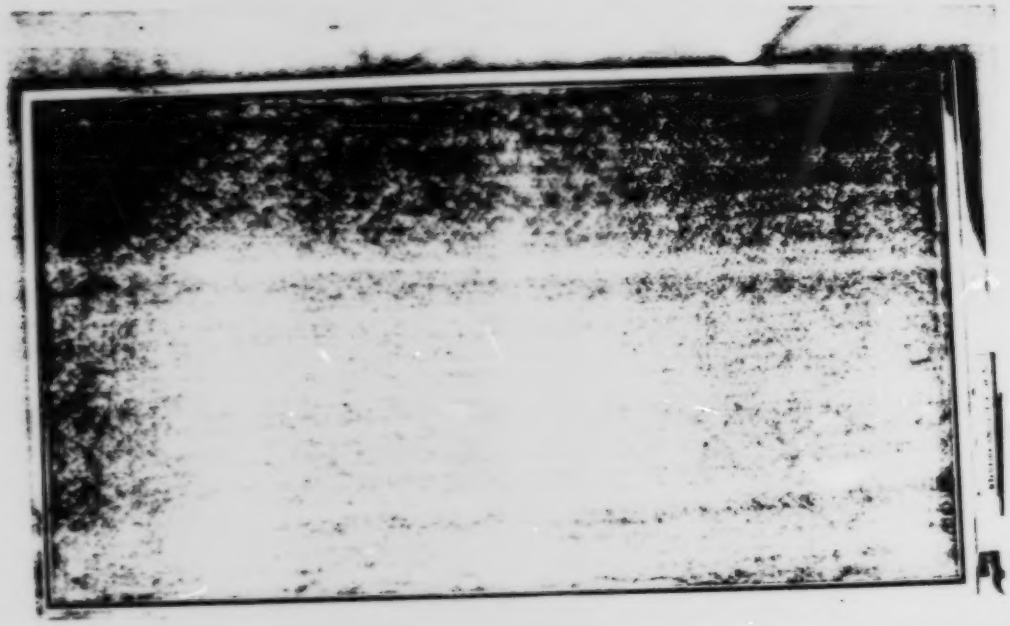


PHOTOGRAPH 7
TEST EQUIPMENT

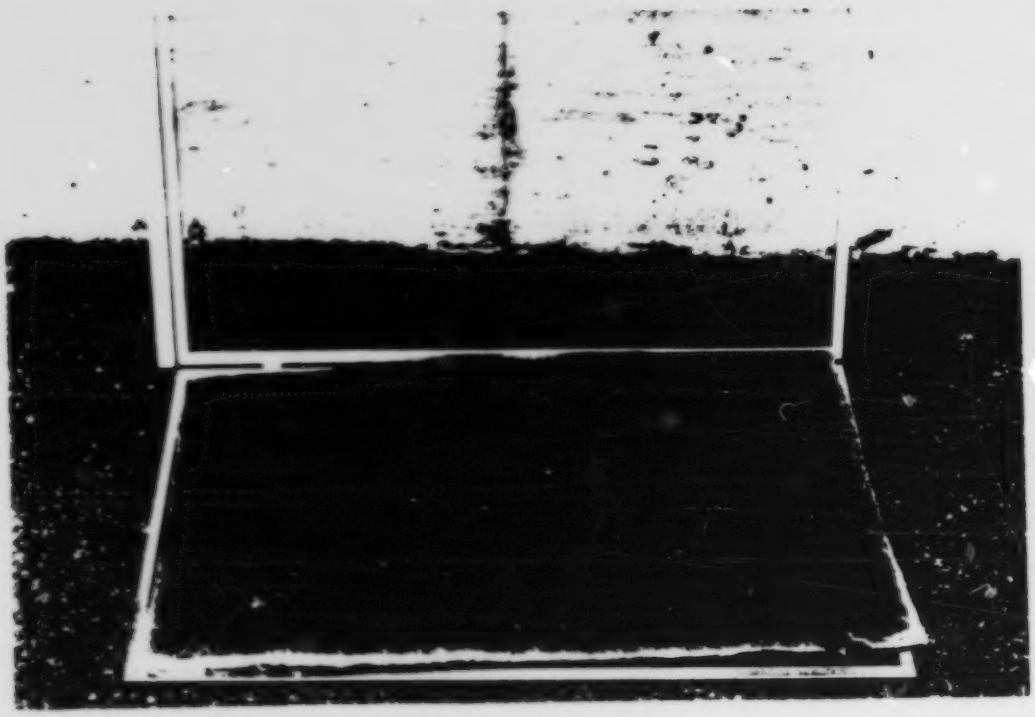
PHOTOGRAPH 8
FIBREGLASS MEDIA FILTER BEFORE TESTING



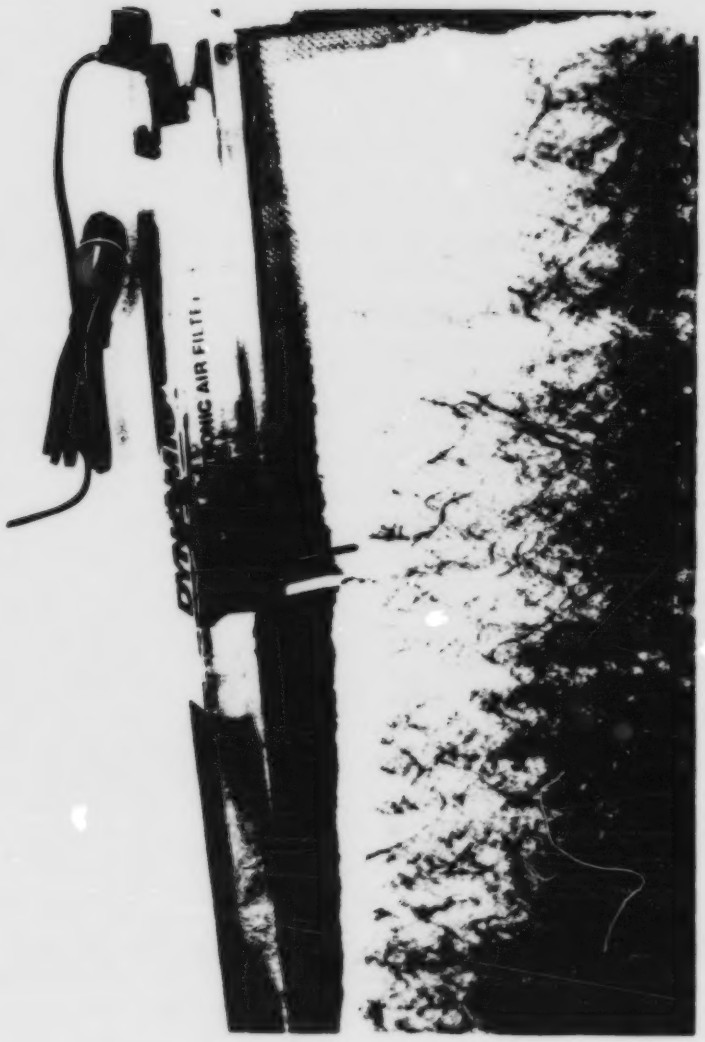
PHOTOGRAPH 9
FIBREGLASS MEDIA FILTER AFTER TESTING



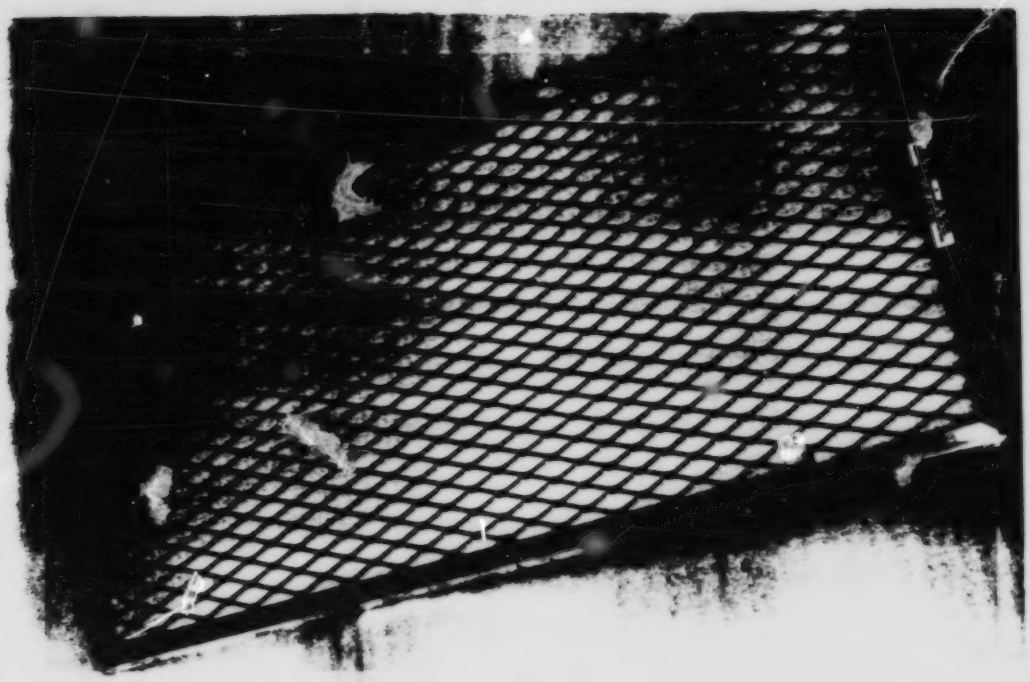
PHOTOGRAPH 10
ELECTRONIC FILTER BEFORE TESTING



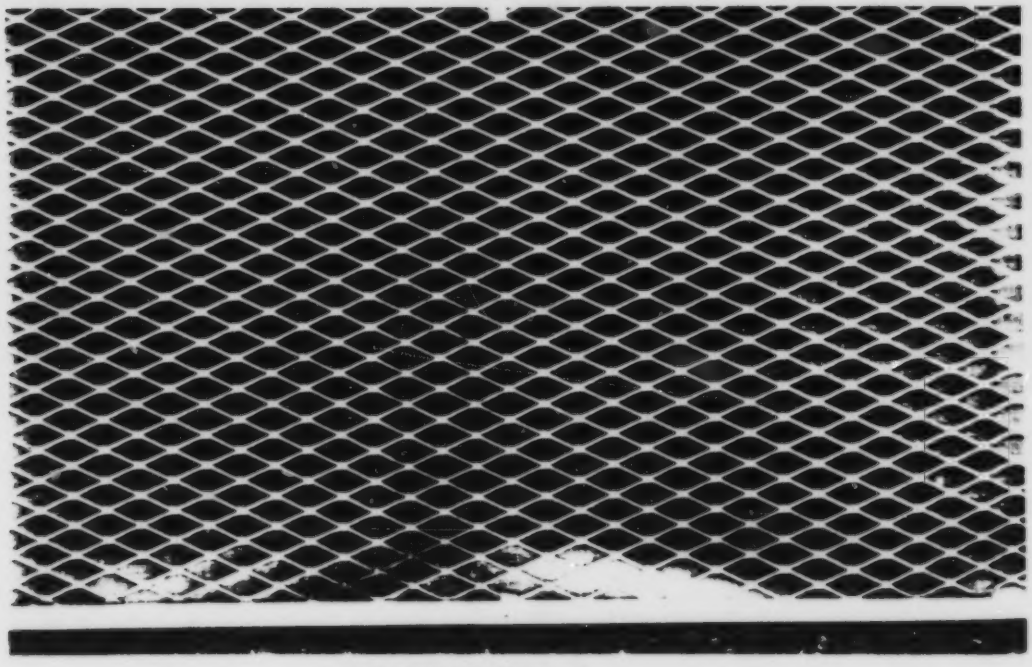
PHOTOGRAPH 11
ELECTRONIC FILTER AFTER TESTING



PHOTOGRAPH 12
ELECTRONIC FILTER - POWER CONVERTOR AND ELECTRODES



PHOTOGRAPH 13
WASHABLE POLYPROPYLENE FILTER BEFORE TESTING



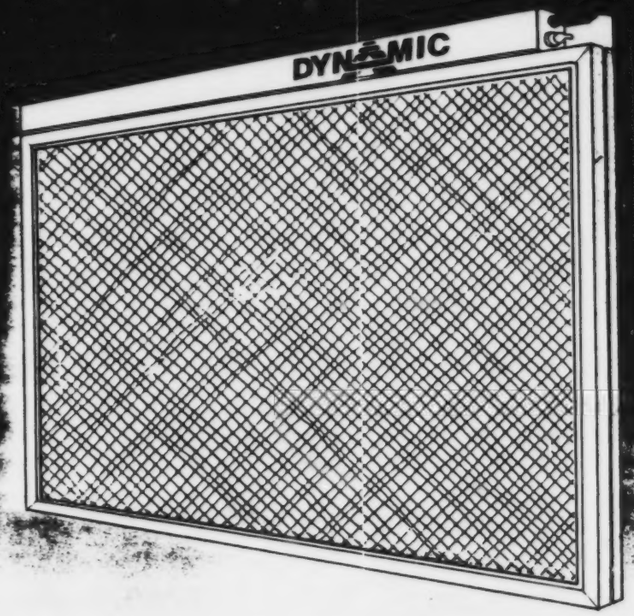
PHOTOGRAPH 14
WASHABLE POLYPROPYLENE FILTER AFTER TESTING

APPENDIX A

"DYNAMIC" ELECTRONIC, ELECTROSTATICALLY AUGMENTED FILTER

SUPPLIER INFORMATION AND ASHRAE TEST DATA

DY C
ELE



[illegible] OF DUST, SMOKE
& POLLEN FROM THE AIR IN YOUR HOME

HEATING & COOLING

KEEPS WALLS, FLOORS, WINDOWS,
DRAPES & FURNITURE CLEANER

WHAT IS A DYNAMIC ELECTRONIC AIR FILTER ?

An exciting new product which, when installed on a central heating or air conditioning system, uses its advanced electronic technology to attract and remove not only large but also very fine airborne particles from your home or work environment.

The majority of household air filters and purifiers currently available are capable of filtering only the **LARGER** of the airborne pollutants.

DO I NEED A DYNAMIC ELECTRONIC AIR FILTER ?

YES! If you have an identified medical problem, (allergies, hay fever or a reaction to tobacco smoke, for example,) the need is obvious. Many of us are fortunate enough to be free of such discomforts, but **DANGER IS STILL IN THE AIR!** Long term ingestion, particularly of the very finest airborne particles, is being blamed for an increasing number of unpleasant symptoms.

The **DYNAMIC ELECTRONIC AIR FILTER** is a simple and effective solution for the removal of almost all commonly encountered airborne particulates.

IS THE AIR IN EVERY HOME POLLUTED ?

YES! The degree varies, depending on where you live or work and on the nature of the indoor activities involved. Typically, suspended in each cubic foot of the air that **YOU ARE BREATHING NOW,** there are hundreds of thousands to **MILLIONS** of potentially harmful particles. Most of these are invisible to the human eye but are continually inhaled, leading to the possibility of serious health-related problems for you and your family.

In addition, recently released authoritative studies show that indoor air pollution is increasing at an unprecedented and alarming rate.

WHY IS THE DYNAMIC ELECTRONIC AIR FILTER MY BEST BUY ?

It's a simple, effective and inexpensive product
WITH a COMBINATION OF ADVANTAGES!
SMALL IN SIZE.
but POWERFUL & EFFICIENT
LOW IN PRICE.
EASY TO INSTALL & MAINTAIN

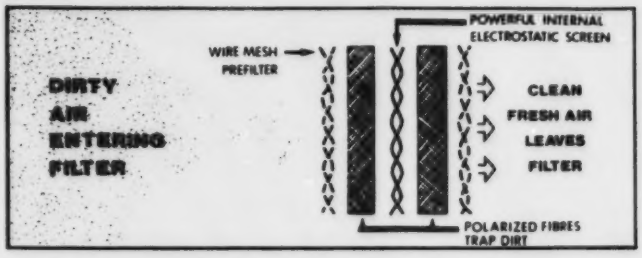
One of the secrets lies in the micro-miniature electronic circuitry which creates a powerful electrostatic action that traps and holds **even the most minute airborne pollutants** from **EVERY ROOM in YOUR HOME!**

THE DYNAMIC ELECTRONIC AIR FILTER — WAY AHEAD IN ITS FIELD!

THE DYNAMIC ELECTRONIC AIR FILTER

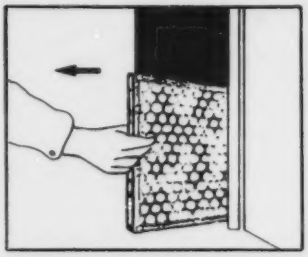
How it works !

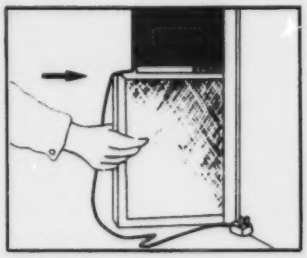
Inside a **DYNAMIC ELECTRONIC AIR FILTER** are two collector pads consisting of tens of thousands of tiny glass fibres. These are given a **STRONG, CONTINUOUS and SAFE CHARGE of STATIC ELECTRICTY,** (via the internal screen,) and, as the polluted air is drawn through the charged pads, the powerful electrical field causes the contaminants in the air to be deposited onto the fibres, (as a magnet attracts a nail,) where they remain trapped until the inexpensive collector pads are replaced.


POWERFUL INTERNAL ELECTROSTATIC SCREEN
WIRE MESH PREFILTER
DIRTY AIR ENTERING FILTER
CLEAN FRESH AIR LEAVES FILTER
POLARIZED FIBRES TRAP DIRT

Easy to install !

Simply remove the disposable cardboard filter from your forced air heating or cooling system and replace it with a permanent **DYNAMIC ELECTRONIC AIR FILTER** of a similar size. Plug the adaptor into the nearest standard electrical outlet and you are ready to enjoy cleaner, fresher air! (Even on 'difficult' systems, a simple, inexpensive mounting bracket is all that is required.)

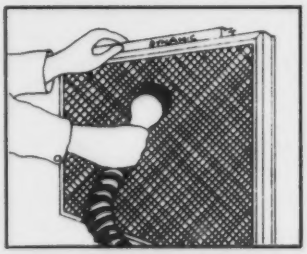


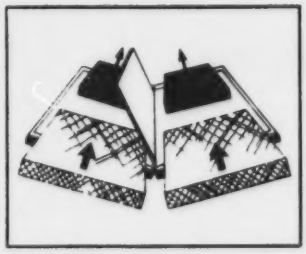


Cleaning is a `snap' !

Approximately every six to eight weeks, unplug the adaptor and remove the filter from your system; vacuum the accumulated dust and lint from the **outside** screens; replace unit and reconnect the power supply.

The collector pads **inside** the filter should be completely replaced at periodic intervals (Typically: every three to six months.) That's all there is to it! Absolutely no washing or messy chemicals.





Sizes to fit all systems !

The **DYNAMIC ELECTRONIC AIR FILTER** is available in fifteen standard sizes, as follows:

12" x 24"	16" x 16"	16" x 24"	18" x 20"	20" x 24"
14" x 25"	16" x 20"	16" x 25"	18" x 24"	20" x 25"
15" x 20"	16" x 21"	18" x 18"	20" x 20"	24" x 24"

CUSTOM SIZES ARE AVAILABLE TOO!
(minimum custom size is 5" x 9", maximum is 24" x 30")

Available from :

SUPER EFFICIENT !

Installing a DYNAMIC ELECTRONIC AIR FILTER in your heating or cooling unit will remove up to 95% of the airborne particles which pass through the return air ducts in your system !

PLUS ALL THESE IMPORTANT FEATURES

- **Safe - runs on low voltage**
- **Full one year warranty**
- **Helps remove household odours**
- **Silent - no `zaps' or `crackles'**
- **Energy efficient - uses less than 1 watt**
- **Cuts down on housework**

110v Adaptor (UL) & (CSA) approved

Manufactured by:
ENGINEERING DYNAMICS LTD.
R.R. 1. Carleton Place. Ontario. Canada K7C 3P1

SUBJECT TO CHANGE WITHOUT NOTICE
PRINTED IN CANADA
NDDS 001 8504

REV. 86/10

INTRODUCTION TO THE DYNAMIC AIR FILTER LINE:

A technological breakthrough in health and cleanliness, the DYNAMIC line of air filters are the modern, high-tech answer to effective control of air pollutants in the home, office, work place, and social places people gather together.

DYNAMIC ELECTRONIC AIR CLEANERS provide an inexpensive, safe and efficient means of fighting indoor air pollution. Properly installed, they will remove practically all particulates, including tobacco and cooking smoke, dust, pollen, textile fibres, animal dander, soot, bacteria and several virus.

The non-ionizing technology produces no potentially hazardous ozone gas, and ensures that the small percentage of dirt particles which do not become trapped when first passing through the filter, will not become electrically charged. (Charged particles are a common phenomenon associated with electronic precipitators and other ionization devices designed for air cleaning, and are largely responsible for discolouration and damage to upholstery, walls and drapes.

A few days after installation one will find that mary household odours due to dust particles will disappear and the air will be easier to breath. The reason is that the DYNAMIC filter eliminates even the very finest particles of submicron size which are the cause of 'heaviness' in the air. People with breathing difficulties due to asthma and other allergies notice the cleanliness of the air most because breathing becomes easier for them. It will also be noticed that dust on furniture and floors will be greatly reduced.

The low cost maintenance of these devices is the essence of simplicity. The panel filters are designed to be fitted into existing air handling units and the free standing and ceiling mount units are also very easily placed. Maintenance is accomplished by opening the filter and replacing the media.

DYNAMIC filters offer cost-effective reliability. Simple to install, these filters consume little power, are inexpensive to operate and offer low cost maintenance-(require no washing or scrubbing.) Less expensive than traditional air cleaning systems, DYNAMIC ELECTRONIC AIR CLEANERS ARE THE OBVIOUS ANSWER TO THE PROBLEM OF INDOOR AIR POLLUTION.

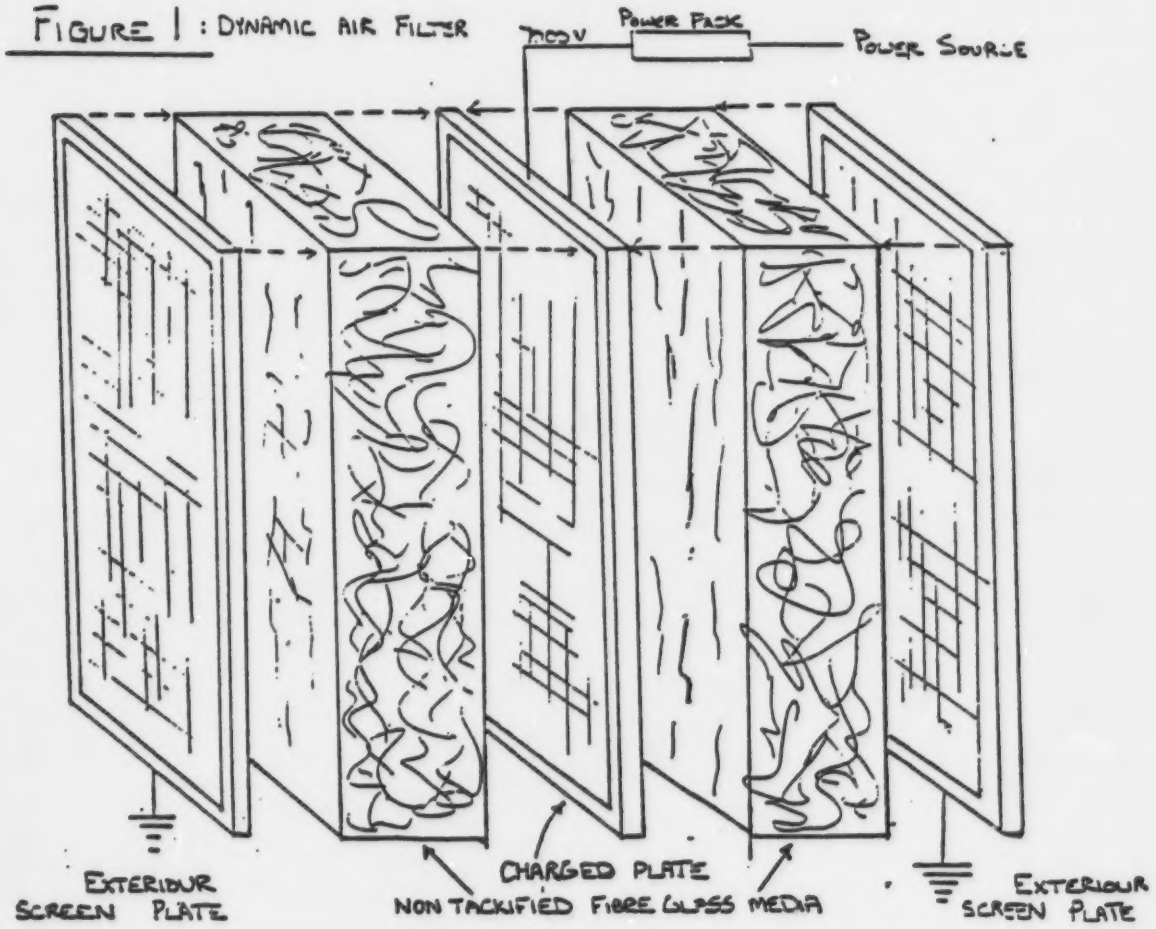
DESCRIPTION OF THE DYNAMIC FILTER:

(i) PRINCIPLES:

The DYNAMIC filter consists of a 110 volt to low voltage adapter which in turn feeds a integral high voltage power supply which has an extremely high internal impedance (about 22 billion ohms) making it very safe for humans, and virtually shortcircuit proof. The 7000 volts is connected directly to a wire mesh screen, which is sandwiched between two non-tackified fibre glass media pads which in turn are contained by two grounded outside screens. The fibre glass media is polarized by the presence of the high voltage screen which in turn polarizes incoming dirt particles thereby setting up an electrostatic attraction between the dirt particles and the fibre glass media. This electrostatic attraction traps the particles in the fibre glass media. Such dirt particles are also trapped by one of two other means: a)by collision (especially large particles) and b) by diffusion, especially medium size particles.

Refer to figures 1 and 2 for further clarification.

FIGURE 1 : DYNAMIC AIR FILTER



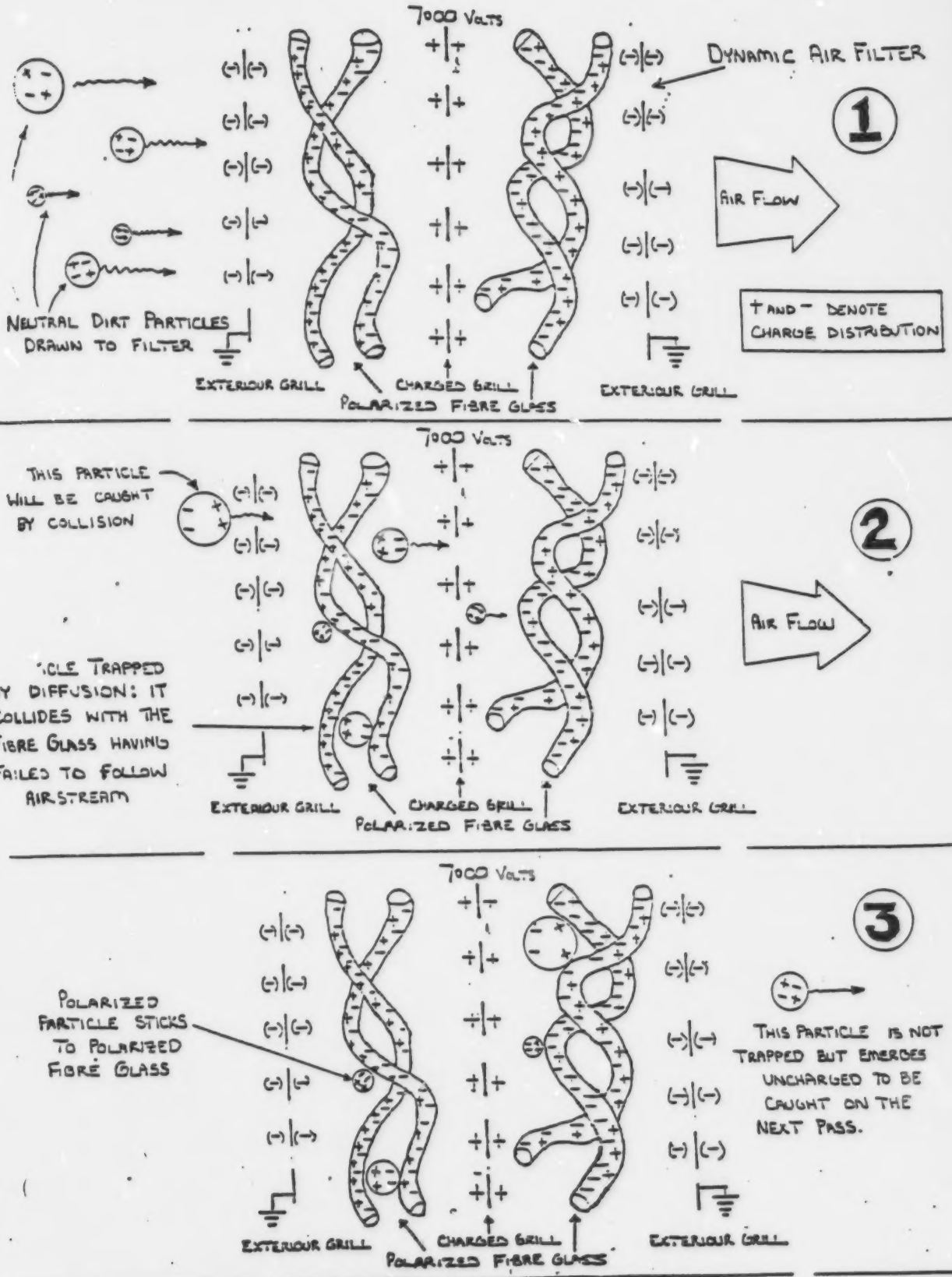


FIGURE 2: DYNAMIC AIR FILTER IN ACTION

DYNAMIC AIR FILTER PERFORMANCE:

(i) A.S.H.R.A.E. Tests:

The DYNAMIC air filter was tested to A.S.H.R.A.E. specifications at the Air Filter Testing Laboratories in Louisville, Kentucky. The results of these tests are given in figures 4 through 7 for both the one and two inch filters.

At first glance it would seem that the A.S.H.R.A.E. test would tend to rate the performance of the DYNAMIC air filter as mediocre: however, when one considers the nature of these tests it is obvious that they cannot reflect the true capabilities of the DYNAMIC air filter. These tests are described below.

(a) PRESSURE DROP TEST:

In this test, fairly coarse dust is progressively loaded onto the filter under test, and the resulting pressure drop increase is noted as a function of loading. This test is conducted at a known air flow rate and is stopped when a predetermined pressure drop point is reached.

A second test is conducted using a clean test filter, in which the pressure drop across the filter is noted as a function of the air flow rate through the filter. The air flow rate is increased from zero to a maximum rate of until a predetermined pressure drop point is reached.

Both of these tests are valid for the DYNAMIC air filter, although it should be noted that the standard A.S.H.R.A.E. dust may have no bearing at all on the real life dust that the filter is required to capture.

(b) ARRESTANCE TEST:

In this test, fairly coarse dust of a known weight is progressively loaded onto a test filter. The increase in weight of the test filter at the end of the test is then noted. The weight of the dust trapped by the filter is then expressed as a percentage of the total weight of the dust presented to the filter. This figure is defined as the percentage arrestance efficiency.

This test is only valid when attempting to determine the effectiveness of a filter against coarse dust. It is absolutely meaningless in attempting to evaluate a filter's effectiveness in removing fine (micron or sub-micron) particles.

This test also involves the use of carbon dust, which being conductive, tends to neutralize the polarizing effect of the DYNAMIC filter as the filter is progressively loaded.

(c) DUST SPOT EFFICIENCY:

In this test, filter paper targets are located upstream and downstream of the test filter, and air, drawn from outdoors, is passed through the system. Using optical methods, the staining of the two paper filters are compared, and are used to calculate the effectiveness, or efficiency, of the test filter.

When subjected to the above test, the DYNAMIC air filter yields poor results. It should be noted however that the strength of the DYNAMIC air filter is when used in a recirculating mode, and against specific challenges. The dust spot efficiency test is therefore not recommended for judging the performance this filter.

Air Filter Testing Laboratories, Inc.

1912 PRODUCTION DRIVE • LOUISVILLE, KENTUCKY 40299

REPORT NO. 352

TEST NO. 1

AIR FILTER PERFORMANCE REPORT ASHRAE STANDARD 52-76

TEST REQUESTED BY ENGINEERING DYNAMICS, LTD.

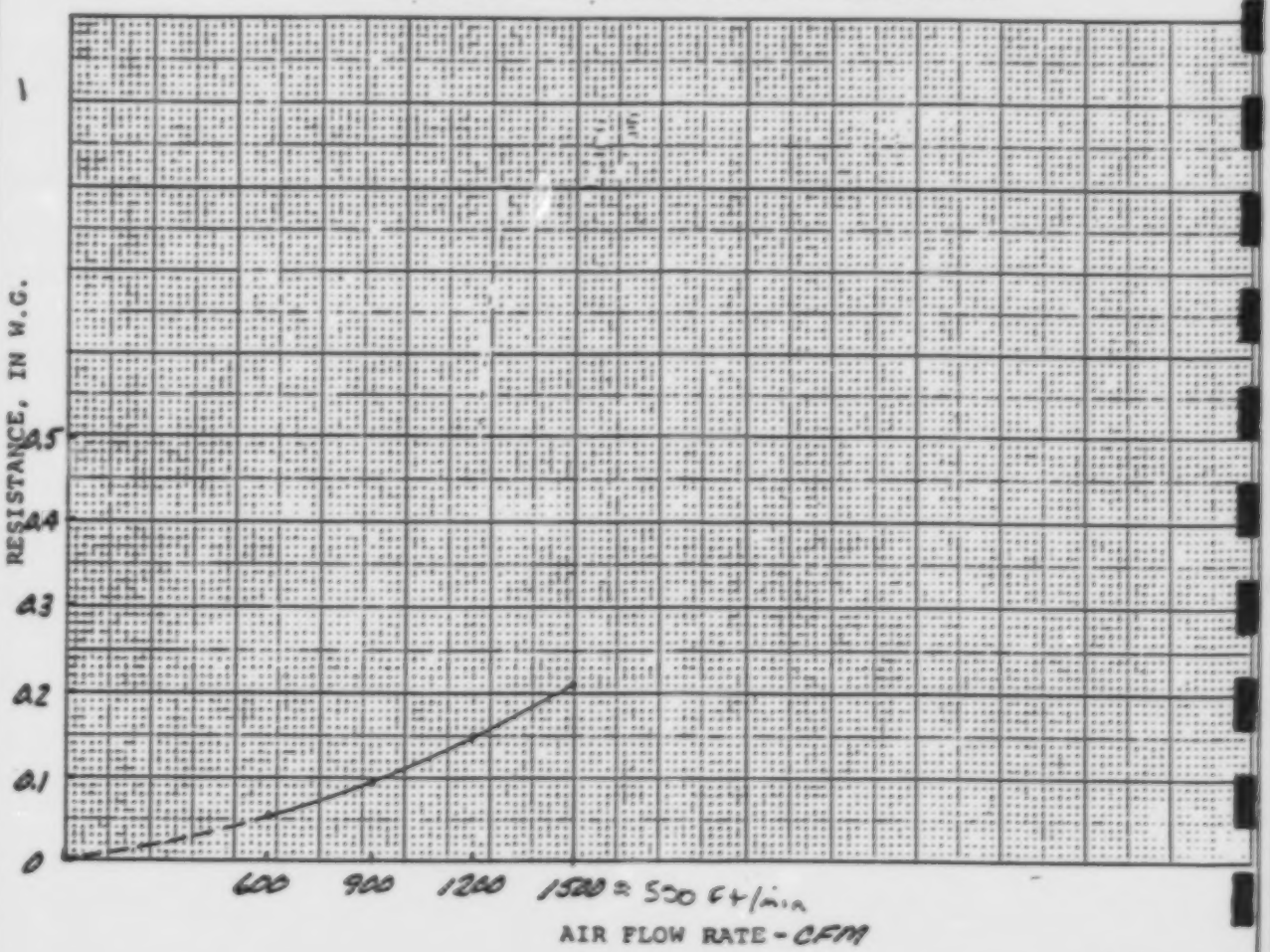
MANUFACTURER ENGINEERING DYNAMICS, LTD.

PRODUCT NAME DYNAMIC ERC

HOW LABORATORY PROCURED TEST SAMPLE FURNISHED BY MANUFACTURER

MODEL NO. 24X24X1 DIMENSIONS 24 IN. H 24 IN. W 1 IN. D

CLEAN DEVICE — AIR FLOW RATE VS. RESISTANCE



DATES OF TEST 4-13-1985

TEST SUPERVISOR O.H.S.

ENGINEERING APPROVAL David J. Murphy Jr.

STATE OF KENTUCKY
DAVID J. MURPHY JR.
6035
REGISTERED PROFESSIONAL ENGINEER

EDL Form 124

AIR FILTER TESTING LABORATORIES, INC.

4632 Old LaGrange Road • Crestwood, Kentucky 40014

• ASHRAE AIR FILTER TEST STANDARD 52-76
STATICALLY TESTED DEVICES

REPORT NO. 3571
TEST NO. 1
SHEET NO. 1

DEVICE TESTED

TEST REQUESTED BY ENGINEERING DYNAMICS, LTD
MANUFACTURER ENGINEERING DYNAMICS, LTD
PRODUCT NAME DYNAMIC EAC
HOW LABORATORY PROCURED TEST SAMPLE FURNISHED BY MANUFACTURER
MODEL NO. 24X24X1 DIMENSIONS 24 IN. H 24 IN. W 1 IN. D

RATED PERFORMANCE DATA FROM MANUFACTURERS	CATALOG NO.		DATED	
AIR FLOW CAPACITY			→	
INITIAL RESISTANCE			→	
FINAL RESISTANCE				
INITIAL ATMOSPHERIC DUST SPOT EFFICIENCY				
AVERAGE ATMOSPHERIC DUST SPOT EFFICIENCY				
AVERAGE SYNTHETIC DUST WEIGHT ARRESTANCE				
ASHRAE DUST HOLDING CAPACITY				

TEST RESULTS

TEST AIR FLOW RATE 1200 CFM	300		→	FPM
INITIAL RESISTANCE	0.15		→	IN. W.G.
FINAL RESISTANCE			0.50	IN. W.G.
INITIAL ATMOSPHERIC DUST SPOT EFFICIENCY				
AVERAGE ATMOSPHERIC DUST SPOT EFFICIENCY				
AVERAGE SYNTHETIC DUST WEIGHT ARRESTANCE			79	%
ASHRAE DUST HOLDING CAPACITY			80	GM

TEST SECTION DUCT SIZE 24 IN. X 24 IN. DUST FEEDING RATE 2.0 GM/1000 CF

SEE BACK SIDE (PAGE 1A) FOR PERFORMANCE CURVES

PHYSICAL DESCRIPTION

FACE DIMENSIONS 24 IN. X 24 IN. NOM.
DEPTH 1 IN. NOM.
MEDIA AREA 3.44 FT^2
TYPE MEDIA GLASS FIBER
TYPE & AMOUNT ACHESIVE NONE

STATE OF KENTUCKY
DAVID J. MURPHY JR.
6035
REGISTERED PROFESSIONAL ENGINEER

DATE 11-4-1984 TEST SUPERVISOR D.H.S. ENGINEERING APPROVAL David Murphy Jr.

AIR FILTER TESTING LABORATORIES, INC.

4632 Old LaGrange Road • Crestwood, Kentucky 40014

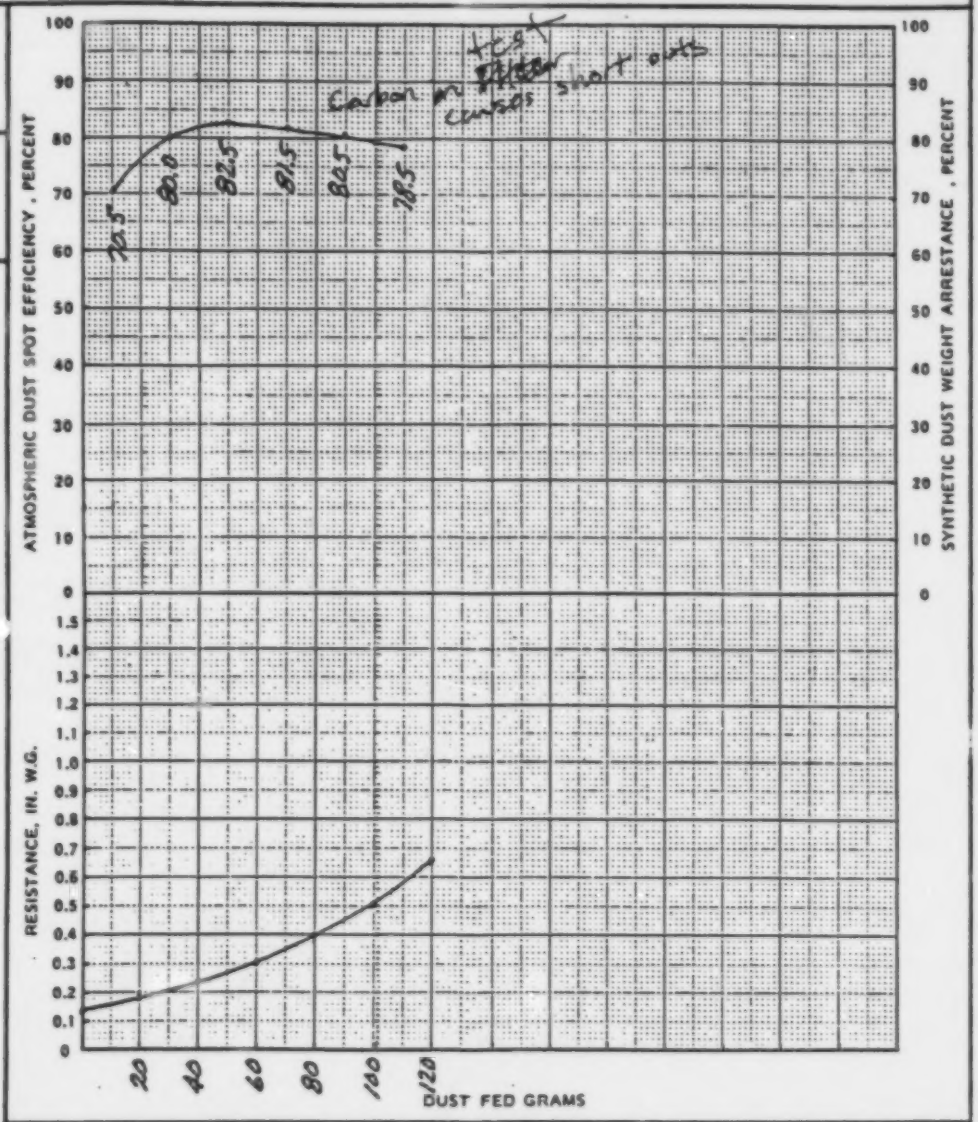
ASHRAE STANDARD 52-76
AIR FILTER PERFORMANCE CURVES

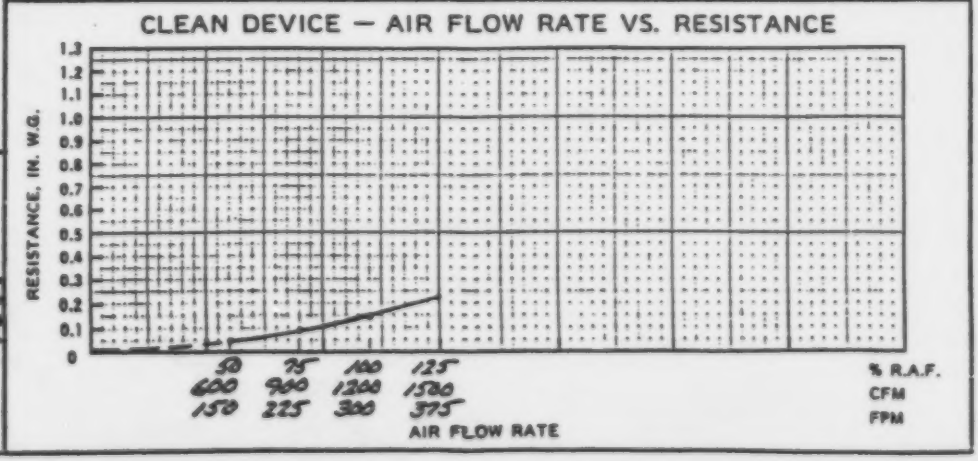
STATICALLY TESTED DEVICES

REPORT NO. 3571

TEST NO. 1

SHEET NO. 1A





DATE

11-4-1984

TEST SUPERVISOR

D.H.S.

ENGINEERING APPROVAL

David J. Murphy Jr.

STATE OF KENTUCKY
DAVID J. MURPHY JR.
6035
REGISTERED PROFESSIONAL ENGINEER

AIR FILTER TESTING LABORATORIES, INC.

4632 Old LaGrange Road • Crestwood, Kentucky 40014

ASHRAE AIR FILTER TEST STANDARD 52-76
STATICALLY TESTED DEVICES

REPORT NO. 3572
TEST NO. 3
SHEET NO. 1

DEVICE TESTED

TEST REQUESTED BY ENGINEERING DYNAMICS, LTD.
MANUFACTURER ENGINEERING DYNAMICS, LTD
PRODUCT NAME DYNAMIC EAC
HOW LABORATORY PROCURED TEST SAMPLE FURNISHED BY MANUFACTURER
MODEL NO. 24X24X2 DIMENSIONS 24 IN. H 24 IN. W 2 IN. D

RATED PERFORMANCE DATA FROM MANUFACTURERS CATALOG NO.			DATED	
AIR FLOW CAPACITY			→	
INITIAL RESISTANCE			→	
FINAL RESISTANCE				
INITIAL ATMOSPHERIC DUST SPOT EFFICIENCY				
AVERAGE ATMOSPHERIC DUST SPOT EFFICIENCY				
AVERAGE SYNTHETIC DUST WEIGHT ARRESTANCE				
ASHRAE DUST HOLDING CAPACITY				

TEST RESULTS

TEST AIR FLOW RATE 1200 CFM	300		→	FPM
INITIAL RESISTANCE	0.28		→	IN. W.G.
FINAL RESISTANCE			1.00	IN. W.G.
INITIAL ATMOSPHERIC DUST SPOT EFFICIENCY				
AVERAGE ATMOSPHERIC DUST SPOT EFFICIENCY				
AVERAGE SYNTHETIC DUST WEIGHT ARRESTANCE			92	%
ASHRAE DUST HOLDING CAPACITY			130	GM.

TEST SECTION DUCT SIZE 24 IN. X 24 IN. DUST FEEDING RATE 2.0GM/1000 CF

SEE BACK SIDE (PAGE 1A) FOR PERFORMANCE CURVES

PHYSICAL DESCRIPTION

FACE DIMENSIONS 24 IN. X 24 IN. Nom.
DEPTH 2 IN. Nom.
MEDIA AREA 3.44 FT²
TYPE MEDIA 4 LAYERS 1/N. COARSE GLASS
TYPE & AMOUNT ACHESIVE NONE

STATE OF KENTUCKY
DAVID J. MURPHY JR.
6035
REGISTERED PROFESSIONAL ENGINEER

DATE 3-1-1985 TEST SUPERVISOR O.H.S. ENGINEERING APPROVAL David J. Murphy Jr.

AIR FILTER TESTING LABORATORIES, INC.

4632 Old LaGrange Road • Crestwood, Kentucky 40014

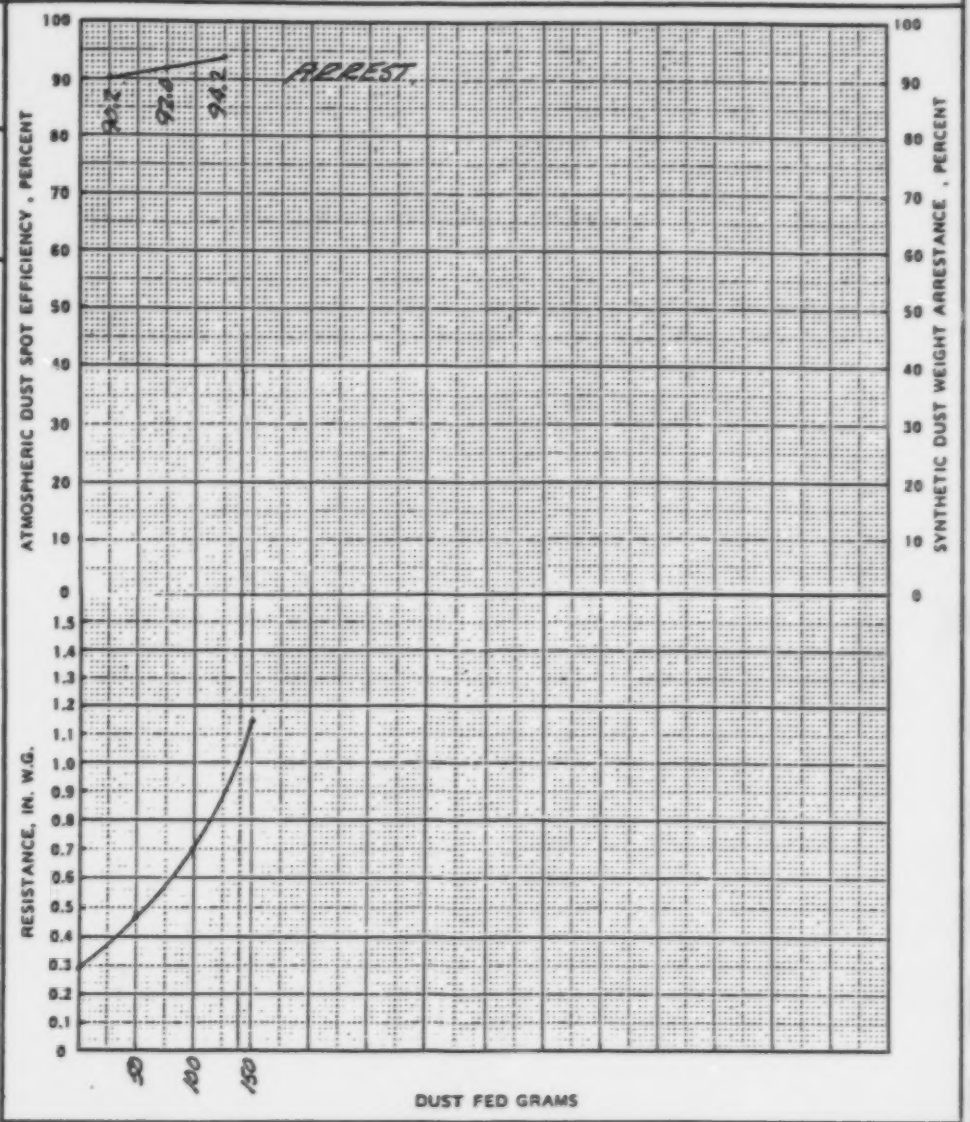
ASHRAE STANDARD 52-76
AIR FILTER PERFORMANCE CURVES

STATICALLY TESTED DEVICES

REPORT NO. 3572

TEST NO. 9

SHEET NO. 1A



DATE

3-1-1985

TEST SUPERVISOR

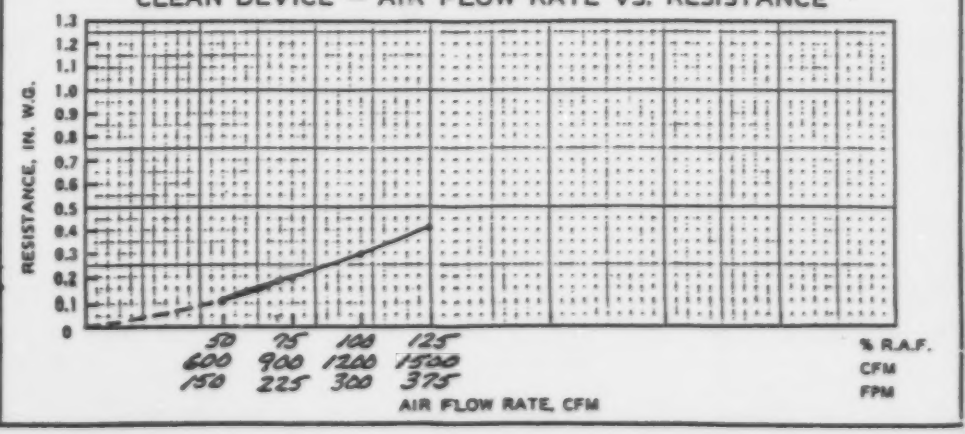
D.H.S

ENGINEERING APPROVAL

David J. Murphy Jr.

STATE OF KENTUCKY
DAVID J. MURPHY JR.
6035
REGISTERED PROFESSIONAL ENGINEER

CLEAN DEVICE — AIR FLOW RATE VS. RESISTANCE



APPENDIX B

"AAA" WASHABLE POLYPROPYLENE, ELECTROSTATICALLY AUGMENTED FILTER

SUPPLIER INFORMATION AND ASHRAE TEST DATA

09 1498 B00

ALL AMERICAN AIR FILTERS, INC.

1871 South Dixie Highway
Pompano Beach, Florida 33360
(305) 785-1926 • Since 1977

PIERRE DEGAGNE
C/O DEL-CAN
2001 THURSTON AVE.,
P.O. BOX 8004
OTTAWA, CANADA K1G3H6

WED. 5/31/88

GENTL EMEN;

NICE TALKING TO YOU THIS MORNING AND WILL LOOK FORWARD TO FURTHER CONVERSATIONS IN THE FUTURE.

I'M ENCLOSING OUR CURRENT BROCHURE WITH TEST RESULTS, ETC., UL 900 CLASS #1 TEST RESULTS FROM SOUTHWEST RESEARCH INSTITUTE, DADE MEMO RE: $1MILLION PLUS SAVING IN TEN YEARS WITH INITIAL RETURN IN 50 WEEKS.,

ALSO ENCLOSING AN EPA ON INDOOR AIR FACTS WHICH I THOUGHT MIGHT INTEREST YOU.

PIERRE, YOU WILL NOTE FROM THE EIGHT PAGES OF USERS OF OUR FILTERS THAT THERE IS QUITE A VARIETY OF USES.

IN HOPES THAT YOUR FIRM WORKS IN OTHER AREAS BESIDES BUSES AND THAT WE MAY BE OF SERVICE IN THOSE CATERGORIES, WE REMAIN.

SINCERELY,

Bob Dargel

BOB DARGEL

ENCL: 1", 2", THICK THIN LINE & THIN LINE SAMPLES.

ENERGY SAVINGS, HIGH EFFICIENCY SELF CHARGING ELECTROSTATIC
PERMANENT / REUSABLE

MEMORANDUM

Date: December 13, 1985

To: Edwin H. Weidman
General Superintendent
Maintenance

Subject: Cost Reduction in Venicle
AC Evaporator Filters

From: Robert J. Dyck
Rail Vehicle Mechanical Engineer
Rail Vehicle Maintenance

The recent trial of AAA Polypropolene Electrostatic reusable filters on Car 152 proved successful. They performed satisfactorily and were easy to remove, clean, and reinstall. The AAA filters was then compared to the Tridem disposable filters now in use. The performance and cost comparisons below show that the Tridem filters performance is only slightly better. However, the cost savings from using the AAA reusable filters are approximately $1,089,082.40 over ten years. The AAA filters have a ten year warranty and will pay for themselves in approximately 50 weeks or 96% of one year.

I have received praise for the AAA filters performance from highly competent sources mentioned in the following Performance Comparison. They have been using AAA filters for many years with great success.

The AAA filters is high performance filters which will save MDC a very substantial amount of money in vehicle AC evaporator filters costs. I fully recommend use of AAA filters as soon as possible in order to realize this cost reduction.

This recommendation is a result of the information contained in the following condensed study.

ECONOMIC ANALYSIS

Analysis and saving are based on the following information:

- Economic comparison based on ten year period. The AAA filter is guaranteed for ten year useful life.
- There are sixteen Tridem disposable filters per married pair which require replacement every month.
- 10% increase in price per year for Tridem disposable filters now in use.
- Assume full use of the entire fleet.

I. Tridem disposable filters:
The cost to change filters on married pair (mp) required for each month would be
(16 filters per mp) ($ 5.60 per filter) = $ 89.60

For the year, the cost per mp would be
(12 months) ($ 89.60/month) - $ 1,075.20

There are sixty eight married pair in the fleet. The cost to replace the disposable filters in the fleet for one year is

($ 1,075.20 mp/year) (68 mp) = **$ 73,113.60 per year**

Assuming the cost of the disposable filters will rise by ten percent a year, the cost to use the disposable filters over a ten year period for the entire fleet would be

$ 73,113.60 (1 + .1) 10 _ 1): .1 = **$ 1,165,242.40**

2. AAA nondisposable filters:

The cost to outfit the entire fleet would be

(68 mp) (16 filters/mp) $ 70.00/filter) = **$ 76,160.00**
This is a one time cost over ten years.

3. **Savings:**
Obviously, the cost differential between the two alternatives is large. The estimated savings in this case is

$ 1,165,242.40 - 76,160.00 = **$ 1,089,082.40**

for a ten year period. This is a considerable savings when considering that it applies to AC evaporator filters alone. The AAA filters will pay for themselves in approximately 50 weeks or 96% of one year.

PERFORMANCE COMPARISON*

PARAMETER	AAA FILTER	TRIDEM FILTER
Dust Arrestance	70%	87.3%
(Atmospheric Dust Spot	Less than 20% initial	16.4% initial
(Efficiency	Less than 20% average	27.0% average
Dust Feed Rate	2 grams per 1000 cfm	2 grams per 1000 cmf
Dust holding Capacity	135 grams	159 grams
Test Air Flow Rate	1200 cfm	2000 cmf
Initial Resistance	0.21 in. W.G.	0.25 in. W.G.
Final Resistance	1.0 in W.G.	1.0 in. W.G.

* Both filters were tested under the same ASHRAE AIR FILTERS STANDARD 52-76. In the above chart, there is a 17.3% difference in Dust Arrestance and a small difference in average atmospheric Dust Spot Efficiency.

The dust Arrestance test uses an ASHRAE prescribed synthetic dust mixture of particle sizes. The Dust Spot test is for very small atmospheric particles which stay suspended in air unless precipitated out. The lower performance in these areas by the AAA filters is not significant in terms of decreasing systems performance on air quality.

The AAA filters were tested on one of our vehicles and performed well. They were easy to clean with our water pressure sprayer. The time taken to clean them was estimated to take no more time that it would take to retrieve disposable filters from stores. They would be lined up and sprayed clean along with the reusable motor filters. Given our maintenance intervals, the Dust Holding Capacity would not be reached.

The Initial Resistance of each filter is approximately the same, when considering that the higher resistance of the Tridem filter was due to a higher Test Air Flow Rate of 2000 CFM. System performance would therefore be the same for either filters where the pressure differential across the filter is concerned.

Several of the many organization using the AAA filter were contacted for testimony of the AAA filter's performance. All indicated that the AAA filter performed better than previous filters by saving electrical costs, saving replacement filter costs, providing better filtration, and keeping evaporator coils cleaners. Three individuals from these organizations are the Director of Engineering for the NW Regional Hospital in Margate Florida, the Chief Engineer of the Boca Raton Hotel, and the General Superintendent of Bus Maintenance for Palm Beach County. Palm Beach County uses the AAA filter exclusively in their buses and will not purchase new buses unless they are equipped with AAA filters. These individuals also indicated that they have been using the same AAA filters purchased five to sevens years ago with no performance degradation.

Finally, the AAA filter meets the requirements of the National Fire Protection Association 701, Section 3.1 and is Classified as a class #1 filter according to UL900, Section 2.

EHW:bc

cc: B. Kane
D. McElroy
A. Rodriguez

SOUTHWEST RESEARCH INSTITUTE

POST OFFICE DRAWER 28510 6220 CULEBRA ROAD SAN ANTONIO, TEXAS 78284 (512) 684-5111

DEPARTMENT OF
FIRE TECHNOLOGY

TELEX 767257
TWX 910-871 1084

May 2, 1986

AAA Filters
1871 S. Dixie Highway, Bay 29
Pompano Beach, Florida 33060

Attn: Mr. Robert L. Dargel

Re: SwRI Project No. 01-8817-314 FINAL REPORT
"Test for Evaluating the Smoke Generation Characteristics of Solid Materials (ASTM E662-83/NFPA 258)"

Gentlemen:

This letter constitutes our final report on your fire-retardant polypropylene filter media material, submitted for evaluation by the referenced test method. The results presented apply to the material tested which you claim to be a representative sample of the material described in this report. The possibility of product variability has not been assessed.

TEST OBJECTIVE AND PROCEDURE

The values for the smoke generation of the material in this report were obtained in strict accordance with the standard procedure. They shall be used solely to define the properties of the described materials when exposed to heat and flames under controlled laboratory conditions. The results shall not be used as measures of smoke hazard under actual fire conditions or for toxicological assessment. The method defines smoke generation under flaming and nonflaming modes which are reported as average Maximum Specific Optical Density.

Test samples are conditioned at 140°F (60°C) for 24 hours followed by stabilization at 70°F (21°C) and 50-percent relative humidity. This method employs 3 x 3-in. (76.2 x 76.2-mm) specimens mounted in a peripherally flanged vertical steel holder at a distance of 2.5 in. (38.1 mm) from an electrically heated radiant energy source (2.2 Btu/s/ft^2; 2.5 W/cm^2) for a period up to 20 minutes. The temperature on the center surface of the back wall is maintained at 95 ± 4°F (35 ± 2°C). The smoke evolved is measured through a light path of 36 in. (0.92 m) in the sealed chamber using a light source and photomultiplier tube arrangement. A minimum of three specimens are exposed as described above and additionally, three or

This report is for the information of the Sponsor. It may be used in its entirety for the purpose of securing product acceptance from duly constituted approval authorities. However, this report or the name of the Institute shall not be used in publicity or advertising.

more specimens are exposed to the identical heat source with a row of six small flamelets across the lower edge of the exposed sample. Millivolt output from the photomultiplier tube is recorded until a minimum value is recorded or for 20 minutes. The dimensionless value is expressed as Specific Optical Density (D_s).

DESCRIPTION AND PREPARATION OF MATERIAL

Date Received:	April 14, 1986
Type:	Air conditioner filter
Color:	White
Construction:	Layered fire-retardant polypropylene filter media (six layers of woven monofilament material)
Fiber:	Polypropylene
Thickness:	2 in. (compressed to 1 in. for test)
Unit Weight:	5.25 oz/ft^2 (kg/m^2), Media only
Substrate Used:	0.25-in. (6.35-mm) glass-reinforced-cement board with 0.5-in. (12.7-mm) inorganic millboard
Date of Test:	April 15, 1986
Cure Time:	1 day, 70°F and 50% Relative Humidity

TEST DATA AND OBSERVATIONS

Number of Specimens Tested: 7

Flaming Mode: 4
Nonflaming Mode: 3

Exposure Time: 20 minutes

Standard Burner/Holder Vertical

D_s = Specific Optical Density

	Flaming	Nonflaming	Average
D_s at 1.5 min	10	2	6
D_s at 4.0 min	57	12	34.5
Time to Reach D_s16, min	2	7.1	4.55
Time to Reach D_m, min	11.2	20	15.6

This report is for the information of the Sponsor. It may be used in its entirety for the purpose of securing product approval from duly constituted approval authorities. However, this report or the name of the Institute shall not be used in publicity or advertising.

TEST RESULTS

MAXIMUM SPECIFIC OPTICAL DENSITY UNCORRECTED = D_m

	Average	Range
Flaming	151	93.72 to 227.2
Nonflaming	31	22.96 to 38.6
OVERALL AVERAGE	91	

Maximum Specific Optical Density Corrected = D_m (Corr)

	Average	Range
Flaming	144	87 to 212
Nonflaming	30	22 to 37
Overall Average	87	

Sincerely,

Carl A. Hafer, P.E.
Manager
Standard Testing Services

Approved by:

Dr. Gordon E. Hartzell
Director, Fire Technology
for
Dr. Robert E. Lyle
Vice President
Chemistry and Chemical Engineering

cc: Mr. Robert J. Dyck
Mechanical Engineer
Metro-Dade Transportation Administration
Vehicle Maintenance
6601 N.W. 72 Avenue
Miami, Florida 33166

CAH/tgm

This report is for the information of the Sponsor. It may be used in its entirety for the purpose of securing product acceptance from duly constituted agencies of authorities. However, this report or the name of the Institute shall not be used in publicity or advertising.

SOUTHWEST RESEARCH INSTITUTE

POST OFFICE DRAWER 28510 · 6220 CULEBRA ROAD · SAN ANTONIO, TEXAS 78284 · (512) 684-5111

DEPARTMENT OF
FIRE TECHNOLOGY

TELEX 767357
TWX 910-871 1084

May 2, 1986

AAA Filters
1871 S. Dixie Highway, Bay 29
Pompano Beach, Florida 33060

Attn: Mr. Robert L. Dargel

Re: SwRI Project No. 01-8817-322 FINAL REPORT
Modified UL 900 Test Method

Dear Mr. Dargel:

We have completed the modified UL 900 fire test on your fire-retardant polypropylene filter media material and following will be a tabulation of the results. The ASTM E84 (UL 723) test apparatus was used as the test device. The air flow was adjusted to 240 fpm (360 cfm) with a natural gas flame of 4000 Btu/min for 3 minutes. The 12 x 17.5 x 2-in. filter was placed 18 in. downstream from the 1-in. NPT burner ports (9-in. centers). The standard UL 900 uses a 21 x 21-in. filter. The smoke was measured using the light-photocell arrangement in the ASTM E84 (UL 723) test apparatus.

Five tests were run as prescribed. Test data is tabulated as follows:

Table 1. Observations

Data	Test Nos. 1	2	3	4	5
Ignition, seconds	3	0	0	0	0
Discoloration, seconds	1	2	2	2	1
Melting, seconds	3	4	3	3	3
Top Half of Filter Melted, seconds	20	10	10	6	5
Flame Advance, in.	12	6	6	0	6

This report is for the information of the Sponsor. It may be used in its entirety for the purpose of securing product acceptance from duly constituted approval authorities, however, this report or the name of the Institute shall not be used in publicity or advertising.

SAN ANTONIO, TEXAS
WITH OFFICES IN HOUSTON, TEXAS, AND WASHINGTON, D.C.

Table 1. Observations (Continued)

Data	Test Nos. 1	2	3	4	5
Afterflame, seconds	0	0	0	0	0
Flying Sparks	None	None	None	None	None
Smoke Developed*	5	5	5	5	0

*Measured as stated above, Red Oak Flooring used in calibrating the ASTM E84 is 100 based on 10-minute test.

Based on the above modified UL 900 test, the AAA Filter is judged to comply with a Class 1 Unit because the filters do not contribute significant fuel when impinged by flame and emit only neglible amounts of smoke. Please refer to SwRI Report No. 01-8817-314 for complete descriptive information of the test material referred to in this report. Should you have any questions concerning the tests or results please contact us.

Very truly yours,

Carl A. Hafer, P.E.
Manager
Standard Testing Services

Approved by:

Dr. Gordon E. Hartzell
Director, Fire Technology
for
Dr. Robert E. Lyle
Vice President
Chemistry and Chemical Engineering

cc: Mr. Robert J. Dyck
Mechanical Engineer
Metro-Dade Transportation Administration
Vehicle Maintenance
6601 N.W. 72 Avenue
Miami, Florida 33166

Enclosures

CAH/tgm

This report is for the information of the Sponsor. It may be used as necessary for the purpose of securing product acceptance from duly constituted approval authorities, however, the report or the name of the Institute shall not be used in publicity or advertising.

United States Environmental Protection Agency | Office of Air and Radiation Washington DC 20460 | February 1988

EPA

Indoor Air Facts No. 3

Ventilation and Air Quality in Offices

BACKGROUND

The air we breathe while at work can affect our job performance, comfort, general sense of well being, and our health. With millions of Americans working in buildings with mechanical heating, ventilation, and air-conditioning (HVAC) systems, their efficiency and effective operation can well determine our indoor air quality. For example, when ventilation is inadequate, excess carbon dioxide produced by people breathing accumulates. Building spaces may become stuffy, and occupants grow drowsy, get headaches, and function at lower activity levels. Other more harmful pollutants from a variety of sources often build up in poorly ventilated work areas and contribute to building-related illnesses.

"SICK BUILDING SYNDROME"

In addition to building-related illnesses which have clearly identifiable causes, improperly designed and operated ventilation systems can also contribute to what is known as "sick building syndrome" or SBS. SBS has physical symptoms without clearly identifiable causes. Some of these symptoms include: dry mucous membranes and eye, nose, and throat irritation. These effects in turn lead to increased absenteeism and reduced work efficiency. The National Institute for Occupational Safety and Health (NIOSH) reports that inadequate ventilation is a cause of many "sick building" cases.

The frequency of "sick buildings" varies by country and by region, but the World Health Organization estimates that up to 30 percent of new or remodelled buildings may have unusually high rates of sick building complaints. While this is often temporary, some buildings become long-term problems which can require extensive investigation and remedial action.

SOURCES OF INDOOR AIR POLLUTION

Indoor air pollution is caused by an accumulation of contaminants that come primarily from inside the building, although some originate outdoors. They may be generated by a specific, limited source or several sources over a wide area, either at certain times or continuously. Common sources of indoor air pollution in commercial buildings include smoking, biological organisms, building materials and furnishings, cleaning agents, office copiers, and pesticides.

CONTROLLING INDOOR AIR POLLUTION

Control of pollutants at the source is an obvious and effective means of protecting indoor air quality and employee health. However, control or mitigation of all sources is not always possible or practical. Adequate natural or mechanical ventilation is, therefore, essential to providing and maintaining good air quality.

In the past, most buildings had windows that opened; "airing out" the indoor space when it became stale or polluted was common practice. In addition, indoor-

outdoor air pressure differences provided additional natural ventilation by infiltration of air through the building shell.

Today most of the newer commercial office buildings are tightly constructed and mechanical ventilation systems are used to exchange polluted indoor air with relatively cleaner outdoor air. When the rates of air exchange are specified by local building codes, they are based primarily on the need to control odors and carbon dioxide levels. Although carbon dioxide is a basic component of outdoor air, its excessive accumulation indoors can indicate poor ventilation. The efficiency of a building's HVAC system and how it is operated and maintained are important to the quality of air in the building.

Concentrations of indoor pollutants are generally directly proportional to the number of sources in a space and their source strength. For example, if two cigarettes instead of one are smoked in an office, twice as much smoke accumulates in the office air.

Indoor air pollution in buildings usually is inversely proportional to the rate at which indoor air is exchanged with outdoor air. If the air exchange rate is tripled and distributed uniformly, in general only a third as much pollution accumulates, and the time for a given amount of pollutant to be cleared will be diminished proportionately.

Air <u>supply</u> rates rather than air <u>exchange</u> rates are usually specified by building codes. Air supply rates are commonly expressed in units of cubic-feet-per-minute per person (cfm/person). In 1981, the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) published its "Standard 62: Ventilation for Acceptable Indoor Air Quality." This voluntary standard specified recommended air-supply rates that were based on providing ventilation to satisfy 80 percent of building occupants. ASHRAE specified 5 cfm/person in non-smoking buildings, and 20 cfm/person in buildings where smoking was allowed. ASHRAE is now considering changing its minimum air-supply rate to 15 cfm/person for all buildings.

In general, increasing the ventilation rate lessens indoor air quality problems in a poorly ventilated building. But even in a well-ventilated building, there may be unusually strong pollutant sources or stagnant zones which impair good indoor air quality. The closer such a source is to an exhaust, the more effective the ventilation. "Spot" exhaust ventilation, like a chemical fume hood, is the most effective. For example, if copier rooms or areas where solvents are used were served by separate exhaust systems, less overall building exhaust ventilation would be required.

COMMON VENTILATION PROBLEMS AND SOLUTIONS

Properly designed, installed, operated, and maintained HVAC systems promote indoor air quality. Poor design, installation, operation, or maintenance of HVAC systems, on the other hand, can create indoor air quality problems. Some common HVAC problems and solutions include:

- **Inadequate makeup air**

  To dilute and displace indoor contaminants, ventilation systems must bring in adequate amounts of fresh outdoor air. However,

because it is costly to heat cold outdoor air in winter and cool hot and humid outdoor air in summer, some building owners and managers greatly reduce ventilation rates--even to zero--during hot and cold spells, causing contaminated air to accumulate inside. In other words, when there is little or no air exchange with the outdoors, a building is poorly ventilated, and indoor air pollution increases. Therefore, provision of adequate makeup air should be ensured at all times.

- **Inadequate design or installation**

  Intermittent air flow: Designs that operate the HVAC system at reduced or interrupted flow during certain portions of the day in response to thermal conditioning needs (as is common in many "variable air volume" installations) may elevate indoor contaminant levels by reducing air flow and mixing, thus impairing contaminant removal efficiency. Therefore, minimum ventilation rates should be determined by thermal conditioning or ventilation requirements, whichever is greater.

  Poor air distribution: Failure to maintain proper temperature, humidity, and air movement can lead office occupants to block supply registers that are too cold or too hot. This disrupts normal air flow patterns. Within a room, locating air supply and return registers too close to each other can result in poor distribution of fresh dilution air and poor removal of indoor contaminants. Finally, placing partitions or other barriers to air movement within a space can also impair air distribution. Therefore, precautions must be taken to maintain proper thermal conditions, properly locate supply and return registers, and properly locate furniture and partitions.

  Poor intake or exhaust location: Building exhaust ducts and outside air intakes that are too close to each other can result in the re-entry of contaminated exhaust air into the building and a build-up of indoor pollution. Location of air intakes near outdoor sources of pollution such as loading docks, heavy traffic, chimneys, trash depots, etc., also makes it easy to introduce contaminants into a building's ventilation system. Therefore, outside air intakes should be carefully located.

- **Inadequate operation**

  Allowing the system operation to lag behind building occupancy or to be turned down or off before non-occupancy can increase both building- and occupant-generated pollutant levels. Similarly, turning the system off both at night and on weekends allows building-generated pollutants to accumulate when the building is empty. Therefore, the ventilation system should be turned on several hours before people come to work, and system shutdown should not occur prior to their going home.

- **Inadequate maintenance**

  HVAC systems must be properly maintained to promote rather than impair indoor air quality. If this is not done, ventilation system filters can become a source of contamination or become plugged and reduce air flow. Also, both humidification and dehumidification systems must be kept clean to prevent the growth of harmful bacteria and fungi. Failure to properly treat cooling tower water to prevent growth of organisms such as legionnella may introduce such biological organisms into HVAC air intakes with potentially serious health consequences. Condensation or

leaks resulting in standing water anywhere in the HVAC system may foster harmful biological growths that can be distributed throughout the building.

VENTILATION STANDARDS AND BUILDING CODES

As discussed earlier, in 1981 ASHRAE published a voluntary industry consensus ventilation standard for acceptable indoor air quality. However, most building codes refer to an earlier version of this standard which was intended to conserve energy rather than promote indoor air quality. That is, many current building codes provide for less ventilation than is now believed required to maintain indoor air quality. And all too often, even these minimal air exchange rates are not enforced. Lack of adequate ventilation rates in building codes and lack of local-level enforcement of existing ventilation rates in many instances also contribute to poor indoor air quality.

AIR CLEANERS

While air cleaners are an important part of an HVAC system, and can be used to filter both particles and gasses, they are not substitutes for adequate ventilation. Air cleaners work best when they have a high filter efficiency and are designed to handle large amounts of air.

Ordinary low-efficiency dust filters are not very effective at removing fine particles such as those in tobacco smoke. High-efficiency air cleaners such as electrostatic precipitators and high-efficiency performance air (HEPA) filters are effective in removing even fine particulate matter, but are more expensive to purchase and operate. All filters require proper maintenance to avoid releasing organic vapors trapped on particulate matter (e.g., tobacco smoke) and biological aerosols, and in the case of electrostatic precipitators, ozone.

Particulate filters are generally ineffective, however, in removing gaseous pollutants. Activated charcoal and other materials can filter some gaseous pollutants (and particulates); however, these systems are expensive and require frequent replacement of the filter material.

RESOLVING AIR QUALITY PROBLEMS IN OFFICE BUILDINGS

Building managers and tenants should work together to improve air quality in office buildings. Areas to address include:

- The general operation and maintenance of the ventilation system and any specific problems observed.
- The nature and number of occupant complaints concerning the indoor air environment.
- Ventilation standards in use; adherence to applicable codes.
- Non-essential tenant practices which may restrict effective operation of the system, e.g., furniture placement, blocking vents, partition changes.
- Restrictions on smoking.
- Identification of pollution sources used by either building management or occupants that may call for steps to remove the source or provide special ventilation techniques.
- Increasing ventilation rates during periods of increased pollution, e.g., painting,

renovation, pesticide use; scheduling of the use of pollutant sources to minimize the impact on indoor air quality.

- Balancing energy conservation with indoor air quality considerations and employee health and productivity costs.

- Frequency and benefits of regular inspection of the ventilating system.

- Identification of areas for follow-up.

SUMMARY

- It is essential to bring fresh outdoor air into buildings to dilute indoor pollutants.

- A well-designed, maintained, and operated ventilation system is essential to provide good indoor air quality in office buildings.

- Poor indoor air quality contributes to worker discomfort and poor performance. In the absence of adequate ventilation, irritating or harmful contaminants can build up, possibly affecting individuals' health.

- An improperly maintained HVAC system can itself generate health-threatening pollutants.

- Air cleaning is an important part of an HVAC system, but is not a substitute for ventilation. Particulate and gaseous filters must be properly maintained to be effective.

- Ventilation rates specified in local building codes are often not enforced and in many jurisdictions the rates are designed to conserve energy rather than promote indoor air quality.

- Energy costs should be balanced with indoor air quality considerations and employee health and productivity costs.

FOR FURTHER INFORMATION

For further information on indoor air pollution, contact your state or local health departments, non-profit agencies such as your local American Lung Association, or the following:

Division of Respiratory
Disease Studies
National Institute for
Occupational Safety and Health
944 Chestnut Ridge Road
Morgantown, WV 26505

Office of Building and
Community Systems
U.S. Department of Energy
CE-13, MS GH-068
1000 Independence Avenue SW.
Washington, DC 20585

Public Relations Office
American Society of Heating,
Refrigerating, and
Air-Conditioning Engineers
(ASHRAE)
1791 Tullie Circle NE.
Atlanta, GA 30329

Building Owners and Managers
Association International
1250 Eye Street NW.
Washington, DC 20005

Additional copies of this Fact Sheet and others in the Indoor Air series are available from:

Public Information Center
U.S. Environmental
Protection Agency
Mail Code PM-211B
401 M Street SW.
Washington, DC 20460

AAA FILTERS

"ENERGY SAVING"

PERMANENT SELF CHARGING

ELECTRO-STATIC A/C FILTERS

GREASE FILTERS

DISTRIBUTED BY: BOB DARGEL

I87I S. DIXIE HWY., BAY 29
POMPANO BEACH FL. 33060
BUS: 785-I926 RES: 77I-5660